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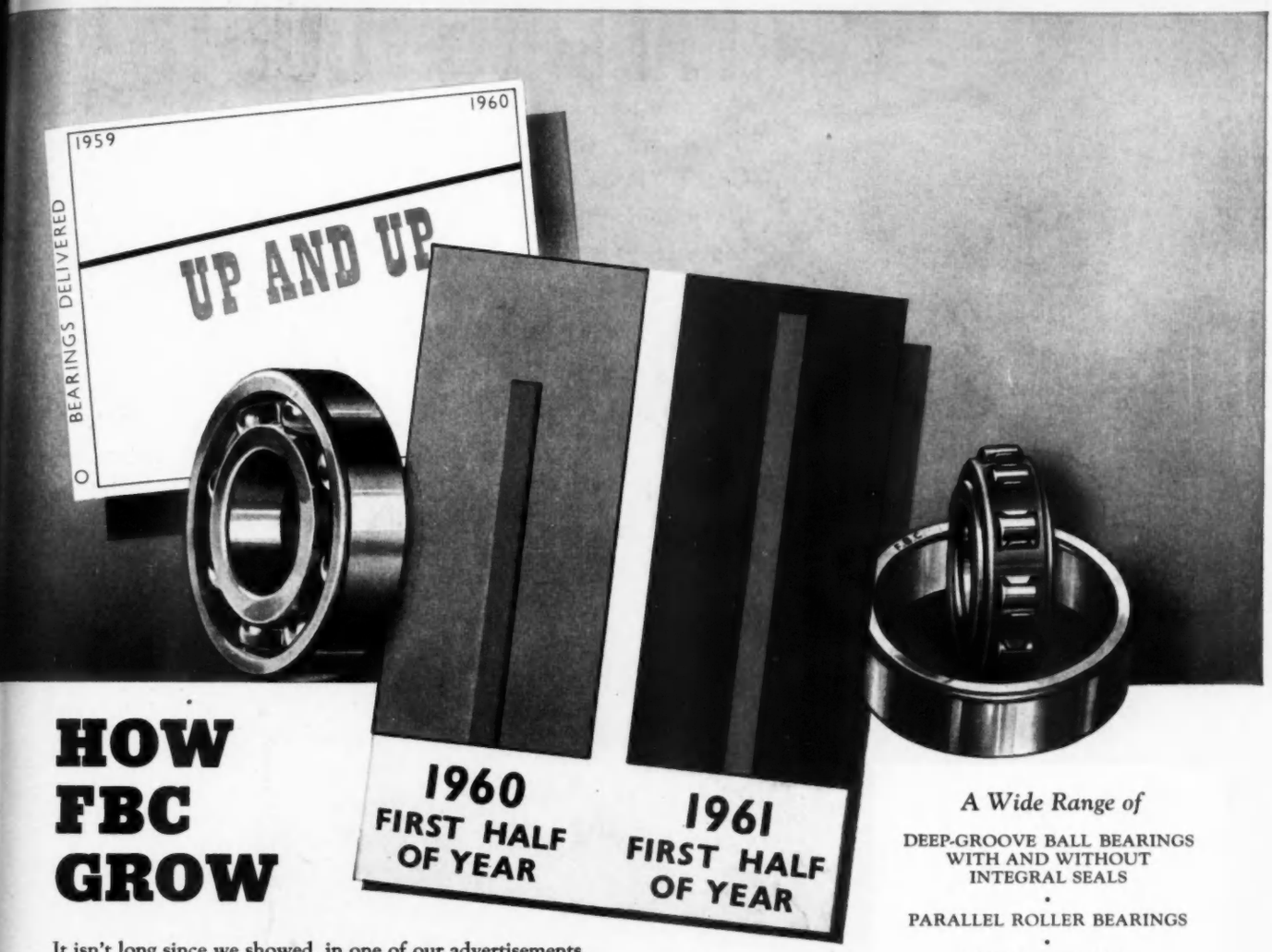

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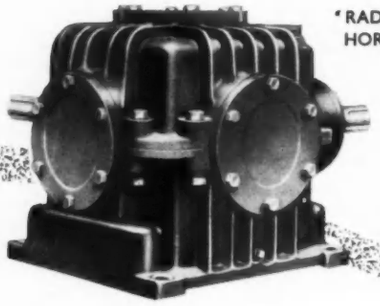

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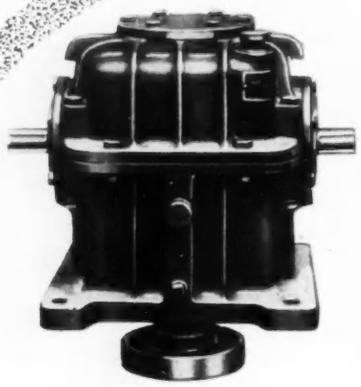

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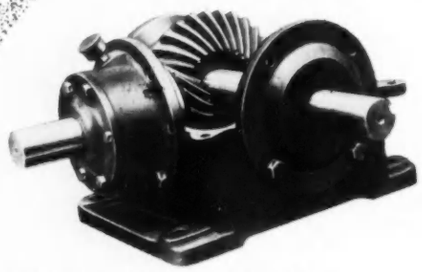

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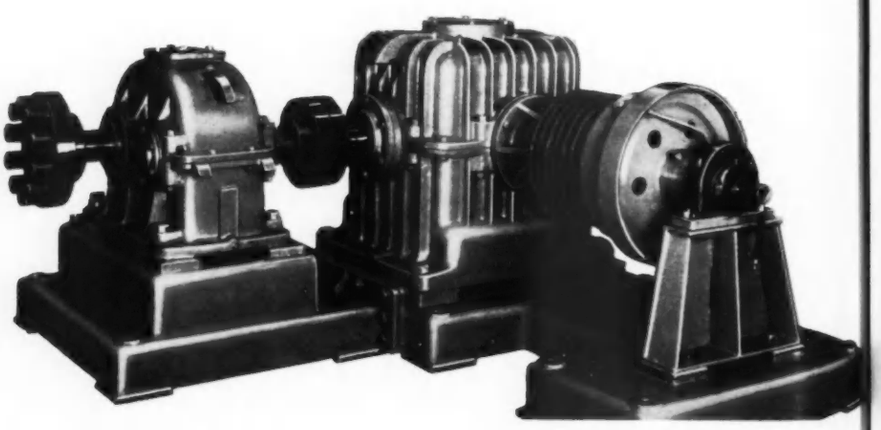

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THE ENGINEER

Established 1856

No. 5527 **DECEMBER 29, 1961** VOL. 212

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THE ENGINEER

No. 5527 DECEMBER 29, 1961 Vol. 212

STALEMATE—OR NO GAME AT ALL?

In spite of the measures taken in the Chancellor of the Exchequer's "little budget" in July when he stressed that "increases in incomes must follow and not precede or outstrip increases in national productivity", the possibility of Britain joining the Common Market, and the additional evidence that has become available since July that any increase in wages — which would result automatically in higher prices — must prove detrimental to Britain's efforts to increase her exports to Europe, wage claims continue to be submitted with, seemingly, a complete disregard for the effect they must have on the economy as a whole. Last week we reported in these columns that the Engineering Employers' Federation had rejected a claim for increased wages and a reduction of hours for some 3,000,000 engineering workers, and had suggested that the unions appeared to be quite insatiable. But nobody expects that the Confederation of Shipbuilding and Engineering Unions will accept this rejection. It is to meet in York on January 11 to consider the rejection and will then without doubt, appeal to the employers again.

Meanwhile, as the New Year approached, the Chancellor of the Exchequer, Mr. Selwyn Lloyd, announced in a debate in the House of Commons that it would be a negation of policy to bring this phase of restraint, the pay pause, to an end prematurely. When it does end, he added, something more must be put in its place than just Government exhortation. Nor did he think that the pay pause could continue on the present lines for the whole period that would be required to work out with both sides of industry a fully fledged national incomes policy. The general scope for wage and salary increases in the coming financial year would be small. There may be room for modest increases in certain cases, Mr. Lloyd said, but any large increases would serve merely to add to inflationary pressures, and would be gained only at the expense of other groups of workers and of the community as a whole, and they would weaken Britain's competitive position in world trade. The Chancellor has invited representatives of both sides of industry to meet him early in the New Year for consultation about arrangements for this intermediate phase.

Earlier in the debate Mr. Lloyd had said that the Government could not impose a national incomes policy without an interference with liberty which would be insupportable, and he had expressed his disappointment at not yet having had agreement from the representatives of the T.U.C. to join in the work of the proposed National Council for Economic Development. Information made generally available about the country's economic circumstances and prospects in such a way that not only those immediately concerned with a particular negotiation but also the community as a whole were able to judge what rate of increase in incomes would be practicable and safe, would clearly carry far more weight Mr. Lloyd said, if it was prepared in a process of consultation, perhaps through the National Council for Economic Development, rather than if it was prepared by the Government. The Government would have to recognise that as part of the incomes policy, appropriate corrective action would have to be taken if aggregate profits showed signs of increasing excessively as compared with wages and salaries. A policy of this sort must concern itself also with expansion, for the promotion of sound economic growth was just as much part of a national incomes policy as the other measures to which he had referred. Again, he added, this was where the National Economic Development Council came in.

On the surface, therefore, the position as the year ends appears to be one of stalemate. Wage claims will certainly continue to be submitted, bolstered by statistics proving that increased productivity justifies them. They will be rejected, the claims being refuted by other statistics proving equally that wage increases are not justified. But sooner or later a more balanced view will have to be taken. The pay pause was imposed last July, and according to Mr. Lloyd it must continue for some time yet. When it ends something more must be put in its place than just Government exhortation. But, the T.U.C., it seems, will not join the Chancellor's planning council while the pause continues, and is thereby cutting itself off from discussions on the formation of a national incomes policy. One can understand its hesitation. The proposed Council, almost inevitably, must propose the limitation of wage increases to figures well below those which individual unions will tend to demand. Many of the leaders of the unions can and do act to restrain their members from pressing forward extreme demands. But were they to join the Council they might seem to the rank and file almost to have gone over to the other "side". It is a difficult decision for the T.U.C. to make; to those union leaders who favour joining it, all honour for their courage, if they carry the T.U.C. on to the Council! We hope they will. For without T.U.C. representation the Council, the formation of which has been begun by the appointment of Sir Robert Shone as Director-General, is likely to seem or actually to become yet another biased advisory body with which the T.U.C. will feel it necessary to do battle. In those circumstances the Council would be worthless for the purpose envisaged by the Chancellor.

CARS, BUSES OR TRAINS FOR COMMUTERS?

Whereas the worries of British Railways relate primarily to road competition, those of London Transport are centred about competition from the private car. The Executive is rather hag-ridden by fears that London may follow the awful example of several American cities which make private car "commuters" so

welcome that public transport has almost ceased to exist. Mr. Bull discussed the situation on December 15 in a lecture before the Institution of Mechanical Engineers, of which we print extracts on page 1084 of this issue. It was an able survey of the problems of carrying commuters into and out of London each day. Naturally the author presented the problems as seen by a public transport body heavily committed to the use of rail transport. Though he admitted that the development of the road system has been inadequate since the war and that its further development has become essential he still seemed to think that the improvements suggested by the Nugent Committee (costing a mere £200 million over twenty years) will be sufficient. Instead of a more active policy of improving the roads he advocates the building not only of the proposed Victoria tube but its extension southwards to Streatham, the extension of the Aldwych line to Waterloo and the extension of the Bakerloo south-eastwards towards Peckham. The cost is estimated at £120 million spread over twenty years. All this is very interesting; but unfortunately little reference was made in the lecture to the economics of these proposals. It is known that, unless fares could be raised without too much loss of traffic, the building of the Victoria line would increase the annual deficit of the L.T.E. perhaps by as much as £2,500,000. It is suspected rather than clearly established that the building of urban motorways, despite their high cost, would yield substantial savings to commercial vehicles, buses and coaches, and cars on business bent, by easing surface congestion. Origin and destination surveys, the work of L.C.C. traffic engineers, and the inquiries of Mr. Colin Buchanan (appointed by the Minister of Transport to study the development problems of roads and traffic in urban areas) may elucidate the point. But in any case it is difficult to avoid reaching the conclusion that as more and more people become able to afford a car so will it become politically preferable to give priority to the improvement of surface transport.

Mr. Bull's lecture was commendably free of the more dubious propaganda put out by the British Transport Commission's publicity people. But it did contain one real "plum." It occurred in a section in which Mr. Bull studied the effect of the staggering of hours of work of commuters and showed that the number of people finishing work in the peak quarter of an hour of the day has been reduced thereby by 20,000. We quote: "This is an achievement of considerable magnitude. By comparison the carrying capacity of a tube railway line in a quarter of an hour is 8,000 in each direction. Or again, 20,000 people travelling by private car, assuming the present average load of 1½ persons per car, would take up road capacity equivalent to twenty-seven traffic lanes, assuming 2,000 cars per hour per lane." The implication to the unwary is that one tube railway line can carry as many passengers per hour as twenty-seven roadway lanes. A little examination shows however that the number of railway lines should be 20,000 divided by 8,000 or 2½. Further examination suggests that a peak railway flow which cannot be sustained for more than fifteen minutes or so is being compared with an average flow of cars along an ordinary urban street. Increasing the number of cars per lane by 50 per cent to simulate peak flow along an urban motorway we arrive at the conclusion that one line of tube railway can carry as many passengers as about seven lanes of motorway carrying only private cars. Is not that figure quite adequate to reveal how uneconomic it becomes to build motorways to carry the whole of the commuting traffic in private cars? Why exaggerate? Of course the more correct comparison, on grounds of convenience, comfort, &c., with coaches carrying many passengers, yields a result less comforting to railwaymen. But were numerous urban motorways built would commuters use such coaches? Or would they prefer their cars? There lies the rub. We do not believe it to be beyond the wit of engineers and architects to plan and build cities pleasant to live in and work in though suited to heavy flows of "commuting" cars. We need not repeat the mistakes made in several American cities. But can we afford it? Are there not better ways of utilising affluence?

APPRENTICES

The question of craft apprenticeship provided one of the main topics for discussion at the sixth annual conference on apprenticeship training, organised jointly by the British Association for Commercial and Industrial Training and the Industrial Welfare Society and held at Brighton towards the end of last month. The five-year apprenticeship system as generally practised in this country was criticised as being out of keeping with modern training methods; this had been proved by practice on the Continent where intensive training methods achieved successful results in far less time. It was pointed out that boys were leaving school at an earlier age and at a lower standard than they were capable of achieving, in order to complete by a reasonable age the five years of service necessary for them to be recognised as craftsmen by both employers and the unions. Furthermore although an apprentice completing his five years training could claim to be a craftsman and demand a skilled rate of pay he had no examination to pass to prove the fact.

These criticisms are certainly not without foundation for it is not to be denied that intensive training on modern lines might well reduce an effective apprenticeship period by as much as two years; alternatively it could permit the apprentice to be far better trained. Admittedly the old practice of using an apprentice as an "odd job" or "tea" boy during his first year has long ceased, but it must also be recognised that nowadays during his last year or so an apprentice often spends quite an appreciable amount of time on production, as distinct from training work; not that experience in production is unnecessary, but it should be curtailed to the minimum in the interests of training. Most certainly an urgent requirement is to institute practical examinations held by independent authority to prove that apprentices have attained a requisite degree of skill in their craft, whatever their period of training.

The two main requirements for bringing apprenticeship standards into line with modern practice are easy to give — an intensive three years of training and a qualifying examination. Then there comes the questions which must be faced by both industry and the unions. Will they recognise three-year trainees who have completed their course and passed their examinations, say at the age of nineteen years, as craftsmen? Will the unions demand and will industry pay such men full craftsman's rates? Perhaps the answer is a qualifying year as an improver at an intermediate rate. These points must be settled by the parties concerned before, as is now obviously very necessary, the apprenticeship system in the country can be revised on modern lines.

OIL AND MUD

The National College of Agricultural Engineering is to be built on a site at Silsoe, Bedfordshire and, by the autumn of 1963, when the new college premises will be open, residential accommodation will be available for 100 students. This first stage of the building will cost £350,000 which will be provided by the Ministry of Education, whilst the industry, through the Agricultural Engineers Association, has offered to give and keep up-to-date tractors and implements to the value of £50,000. The prospectus, published a week ago, marks an occasion which has been long awaited in both the engineering and agricultural machinery industries, and indicates, as Dr. P. C. J. Payne, principal of the new college pointed out at a press conference held recently, that agricultural engineering, like chemical and mining engineering, has now advanced to a point where much of it can be studied as a technology in its own right. Of the two courses mentioned in the prospectus and reviewed in our issue of December 15, the three-year Associateship Course is intended to provide the "sheet anchor," Dr. Payne said, by which the college will set its standards, and it is intended to build into this the best undergraduate-type training in professional agricultural engineering obtainable anywhere in the world. The Associateship Course is meant to enable students to attain the standard of a general University degree.

Sir Gilbert Fleming, chairman of the governors, pointed out at the conference that the college had been located in the country deliberately because it was thought the course should be a "muddy-booted" affair. Elaborating on this theme, and possibly associating it, mentally, with engineers liberally daubed with oil, Dr. Payne went on to suggest that the college should be a mixture of oil and mud. Whilst the mental picture conjured up of this glutinous emulsion might not appear to be a happy analogy, we feel sure that engineers and agriculturists will agree that the qualified students sent out by the college will contribute greatly to the development of mechanised agriculture both at home and overseas.

We can only lament the fact that this project has taken so long to get under way and that the first intake of students for the three-year course will number only twenty. As long ago as the spring of 1955 the President of the Institution of Agricultural Engineers drew attention to the need for a central college, and stressed the importance of adequate training for professional engineers who were anxious to devote their talents and energy to mechanised agriculture. But the embryo is now formed, and sincerely we wish the resulting college every success.

DOES DAYLIGHT MATTER?

It has been said that daylight is one of the few things man gets for nothing in this highly-organised (and expensive) world. Certainly it is something of which man likes to have his full allowance. Who prefers the short winter days to the long ones of summer, irrespective of the weather? Who will not grumble at, or at least notice, those occasional days in a British winter when full daylight refuses to appear at all, and a dismal gloom is nature's substitute? The normal human being is sensitive to daylight. Granted that man welcomes daylight, what are we to say of those industries where, in his normal daytime work, he has to do without it? We are not thinking of those activities, such as underground mining, where there is no choice; nor, in the present context, of the denizens of the deeper basements of modern office buildings. We refer to the factories — and there are more of them than may generally be realised — where daylight is deliberately excluded from the workshops.

Sometimes good reasons are given for building without windows. In some heavy industries, for example, it is often claimed that because the process work is productive of smoke, fumes and dust, it is cheaper to provide a reasonable standard of artificial light than to incur the expense of continuous window and roof light cleaning. That may be so; figures can be very convincing. But we can recall some singularly gloomy caverns where this principle was applied. We have in mind, on the other hand, some large, light workshops engaged on the same processes, where the management evidently felt that, if daylight was not free, it was worth while to let it in. At the other extreme there are some factories where the nature of the work being done demands scrupulous cleanliness, and it is necessary to seal the buildings, install air conditioning and have air-lock entrances. In such circumstances, ordinary windows being unsatisfactory, the problem is sometimes solved by having no windows, and relying only on artificial light.

Both kinds of factory operate successfully. Some of them provide very good — even extremely good — working conditions, except in one respect. In winter time it is possible for a man employed in such a factory hardly to see daylight at all for long periods, except at week-ends or other off-duty times. Perhaps the general working conditions are such, in the minds of the workers, as to compensate for lack of daylight, or perhaps they never even notice it. But is it really right to turn men into troglodytes; for that is what they are, in effect, however good the conditions in the cave may be? It would be interesting to hear some professional opinions on the long-term medical and psychological effects of being deprived of daylight.

The Engineer—100 Years Ago (DECEMBER 27, 1861)

Perkins's Steam Gun

Our issue of December 27, 1861, contains an illustrated description of a steam gun invented by Jacob Perkins. Steam was generated at 3000 lb per square in. in a coil of pipes and passed through a series of "vessels" (the purpose of which is not clearly explained) to the "gun," an ordinary gun barrel, to which the steam was admitted by a stop valve. Entry of the bullets or balls, from a hopper or chute over the gun was through a manually-operated two-way breech mechanism. We did not know what would be the velocity of the bullets, but calculated that if it were assumed to be the same as the Enfield bullet (1300 ft per second), and the bullets weighed one ounce each, the gun, firing 60 bullets a minute would need 4½ h.p. to operate it.

We felt that the steam gun, though it could undoubtedly be made to project bullets with great rapidity and force, was unlikely to be a success in view of "... the liability to injury, if not to constant derangement, of so many delicate appendages, such as the pump and gauges, and the necessity for supplies of fuel and water." In fact there is no record of such a gun being used in warfare until 80 years later when, in the war of 1939–45, over 1000 ships were fitted with a form of missile projector which, though of a different pattern from that designed by Perkins, was nevertheless a steam gun.

Let's Adopt the International M.K.S. System

By H. S. HVISTENDAHL, B.Sc.(Eng.), M.I.C.E., M.I.Mech.E., M.I.E.E.

The desirability of abandoning our traditional system of units in favour of the metric system has been a constantly recurring subject of discussion, but so far the arguments against have outweighed those in favour of any change other than the definition of our old units in terms of international metric standards instead of our original ones. Recent developments, such as our impending entry into the European Common Market on the one hand, and the unanimous agreement among all international technical committees concerned on the M.K.S. system of units as a single common system of units for all technical purposes on the other, have however now vastly strengthened the case for the speedy abandonment of our traditional system. The article reviews the case for discarding that outdated system in the light of these developments, and offers suggestions as to how we can start on the first stage of the replacement of our old units by those of the International System, thereby preparing the way for our ultimate adoption of the system in its entirety. Suggestions of this nature have always been the subject of controversy and the author wishes it to be clear that the views expressed are simply those of one who has given much thought to the subject.

THE traditional engineers' system of units, still widely used in English textbooks on the manifold branches of mechanical engineering, has two serious disadvantages. Firstly, it causes their mathematics to be loaded with a vast amount of idle ballast needed to reconcile the motley varieties of arbitrary units inherited from less enlightened generations, and secondly, what in this dawning age of nuclear power and space conquest is a no longer tolerable fault, it causes the acceleration of gravity, g, to intrude where gravitational attraction of the earth is not concerned and to be omitted precisely where earthly gravitational attraction is involved.

The latter inherent fault is a consequence of the engineers' or gravitational so-called "system" being not a system, but to use plain words, a muddled mixture of two systems. Whilst it professes to use the pound, the foot and the second as its fundamental units of mass, length and time, the units of the quantity W/g, in which it always expresses mass whenever inertia forces have to be calculated, are not pounds, but units of mass 32·174 times larger than the pound. The reason is, of course, the fact that the force unit belonging to the system's professed choice of fundamental units, namely, the force which will cause a body of one pound mass to be accelerated at the rate of 1ft/s², or poundal, is ignored and in its place an arbitrary incoherent, 32·174 times greater unit substituted, defined by the intensity of the mutual gravitational attractive force between the earth and a body of one pound-mass located at sea level and at 45 deg. latitude. The unit of mass, which when acted upon by this—for some purposes expedient but nonetheless incompatible—unit of force is accelerated at the rate of 1ft/s², is of course 32·174 times greater than the pound mass. It has been given the name "slug" and the fundamental units of the system to which the pound-force belongs are accordingly the slug, the foot and the second.

To those having to work in English units, but whose logic is unable to countenance the irrelevant use of the gravitational pull W on a body at some conventionally agreed place as a measure of what by definition is a fundamental physical property of the body, namely its mass, and who accordingly regard any datum quantity of pounds of matter as meaning its mass m, the divisor 32·174 is simply a dimensionless ratio for converting the datum number of measure of the mass in pounds into its number of measure in slugs, in order that inertia forces given by the fundamental law $F=ma$ shall be expressed in pounds-force.

Despite the initiative of these more discriminating minds, the majority of authors of English language textbooks concerned with the various applied branches of mechanics, fluid-dynamics and thermodynamics, seem however reluctant to abandon the loose practice, originated in times when mass was still being confused with weight and complacently retained in the engineers' system, of expressing any mass in terms of its conventional weight W, regardless of whether or not earthly gravitational attraction is involved in the phenomena concerned. Just as in the case of those who consciously employ the slug-foot-second system, so too, those who continue to use the traditional system must convert datum quantities of matter given in pounds into slugs for the calculation of inertia forces in pounds-force from the fundamental law $F=ma$. Whereas, however, in the former case the conversion is evident, in the latter it is obscured by a befogging artifice requiring the datum quantity of pounds to be thought of as the gravitational force W exerted on the mass at a place where the acceleration of gravity has the conventional value $g=32·174$ ft/s², and that that force then be divided by this conventional value of g, thereby concealing in the resulting pons-asinorum creation W/g, the inescapable elementary conversion of the original number of pounds into slugs.

As a consequence of this senseless elaboration of a simple conversion of mass units, the acceleration of gravity g obtrudes persistently without physical reason into equations relating to phenomena where earthly gravitational attraction is in no way involved, for example, in the expression for the energy stored in a rotating flywheel $E=\frac{1}{2}(W/g)k^2\omega^2$ which at any given speed ω is, of course, the same whether the flywheel happens to be on the surface of the earth, or anywhere else in space. Conversely, precisely where earthly gravitational attraction is a dominating factor, as in the pressure exerted by a column of liquid, or by any other load, the absence of g in the equation $p=W/A$ fails completely to show how W, and therefore how p, depends on the local intensity of gravitational attraction.

Further, the fact that the symbol W, referring to its conventional weight, and not its proper symbol m, is used to represent mass, leads to the paradoxical conclusion that the de-facto third unit of our traditional system is not the pound-mass, but the pound-force.

In a futile attempt to resolve the dilemma as to which should be regarded as the actual third fundamental unit, the creators of the hitherto generally employed metric equivalent of our engineers' system did, in fact, define the kilogramme-force as the third fundamental unit of the metric technical system. All they thereby succeeded in doing, however, was to make that system even more confusing from the physical standpoint than the English one, as in addition to leaving g to appear in the wrong place in respect of the presence or absence of gravitational action in purely mechanical phenomena, gravity was thus also made to enter illogically into properties of matter such as specific heat and thermal conductivity, owing to such properties having to be referred to unit kilogramme weight of matter. Oddly enough, having defined the kilogramme-force as the third fundamental unit, these creators of the metric technical system do not seem to have bothered about giving a name to the coherent unit of mass of the system, and only recently has the name "Hyl" begun to be accepted for this unit of their quantities G/g, corresponding to the slug in the case of our quantities W/g.

The inconsistencies of the metric technical system as well as of the English system were, of course, unacceptable to the methodical minds of the world's scientists, who long ago got together to establish the c.g.s. system, which name they, however, thought necessary to prefix with the attributive, "absolute" to mark the fact that here, in contradistinction to the "gravitational system", the word system really meant system. It is fitting to recall that the initiative which led to this momentous achievement was taken by the British Association for the Advancement of Science. Although the c.g.s. system has been of inestimable value to mechanical engineers in the assimilation of basic principles, most of its units unfortunately proved to be far too small for practical purposes.

The first serious attempt at instituting a coherent system of units for mechanical engineers modelled on the c.g.s. one, but with units suitable for practical use, was made in France, where the metre-tonne-second system received legal recognition in 1919, and where it made slow, but steady progress, not only amongst the academicians, but also in industry, notably in connection with steam turbine plant for electricity generation. In the meantime, however, groups of mechanical engineers in various countries gradually awakened to the fact that the M.K.S.A. system with the metre, the kilogramme-mass, the second and the ampere as its fundamental units, proposed at the turn of the century by a then young Italian engineer of the name of Giorgi, adopted first in 1935 by the International Electro-Technical Commission on behalf of all electrical engineers and, after extension to include the Kelvin temperature degree and the candela unit of illumination, in 1956 by the International Committee of Weights and Measures, was equally ideally suitable for practical use by mechanical engineers.

The International System is also recommended by the International Standards Organisation, The International Union of Pure and Applied Physics and the International Union of Pure and Applied Chemistry, and the trend towards its adoption for mechanical as well as for scientific and

electrical engineering purposes is now rapidly gathering momentum among engineers of the leading Continental nations. In Switzerland the largest engineering concern has for the past six years used M.K.S. units in all thermodynamic calculations, and elsewhere also, many publications on mechanical engineering subjects, among which Professor Traupel's treatise on thermal turbo machines is outstanding, have appeared employing M.K.S. units.

In Germany, the M.K.S. system has been recommended by the V.D.I. since 1958. The V.D.I. realised, however, that an immediate complete transition to that system was not practicable and whilst advocating the M.K.S. units as the preferred ones, the recommendations therefore allow existing units of the old system to continue to be used where they are not affected by what are in short the following changes :

The measure of quantities of matter shall be in kilogrammes-mass, and not as hitherto in kilogrammes-weight and the name " kilogramme " and its abbreviation " kg " shall in future mean the kilogramme mass only.

All properties of matter shall be referred to the kilogramme mass and not as hitherto to the kilogramme weight.

Where still employed, the old kilogramme-force unit shall always be distinguished from the kilogramme mass unit by the use of the name " kilopond " or its abbreviation " kp."

As a result of these changes, only units involving the old kilogramme-force yardstick, now unambiguously discriminated from the mass unit by a distinctive name, and such other units of the old metric technical system as the kilogramme-calorie and the horsepower, will differ from those of the International System, and under the impact of the increasing number of publications in M.K.S. units by far-seeing eminent authors such as Professor Traupel as well as the influence of graduates educated in the use of the M.K.S. system, it is to be expected that those remaining redundant units of the old technical system will soon become obsolete and their place naturally taken by the M.K.S. ones.

Resolutions similar to those of the V.D.I., or other recommendations in pursuance of the same objectives, have also been taken or are now being proposed in other Continental countries, notably in Austria, Holland, Sweden, Switzerland and the U.S.S.R.

It requires no special powers of clairvoyance to foresee that the other nations of the world now using, or who will go over to, the metric measures, among which will almost certainly be included the self-governing African and Asian members of the Commonwealth, will in due course adopt the international system in its entirety for all technical purposes. In all such countries mechanical and electrical engineers alike will, together with physicists and chemists, have the immense advantage of a single common set of units which, with the aid of the standardised abbreviations for multiples and sub-multiples, ranging from T(Tera$=10^{12}$), down to p(pico$=10^{-12}$), enabling any unit to be instantly scaled up or down to give a convenient number of measure, will in the simplest possible manner, cover all the needs of their professions.

In this modern age, the welfare as well as the political standing of a nation, more than ever before, depends on the achievements of its engineers. Moreover, in addition to our old rivals in the engineering field, new and formidable ones are now having to be faced, and we therefore can ill-afford to procrastinate as to what can, and should, be done to ensure that in their efforts to maintain our position among the leaders, our mechanical, as well as our electrical, engineers shall not be needlessly handicapped by an archaic, time-wasting muddled collection of hotch-potch units, incomprehensible not only to the customers we hope to find in countries of the European Common Market, but to the vast majority of engineers in the rest of the world.

In setting about this task we must, evidently, consider what difficulties are likely to arise from the present state of affairs. One of the first objections likely to be raised on this count to any suggestion of change, is the fact that most of our standard components are based upon, and much of our production plant is suitable only for manufacturing to, English dimensions. The answer to this objection is that the need, where necessary, of using standard components to inch sizes and/or of marking any other dimensions on shop drawings in inches, until willy-nilly, under the compelling forces of the changing pattern of the industrial world, we are ultimately obliged to go over completely to International I.S.O. standards is no reason to debar our mechanical engineers of the immediate future from the benefits of the beautiful simplicity of the International M.K.S. System during their training and in practical work thereafter, with all the advantages accruing from the use of the same unit language as the overwhelming majority of engineers and technicians elsewhere. Proof of this is provided by the fact that any similar need for marking dimensions on shop drawings in inches by manufacturers of electrical machines and apparatus has never debarred our electrical engineers from employing, in common with all other electrical engineers, International units based on metric standards. Indeed, much British mechanical as well as electrical equipment is already being designed and manufactured without any difficulty to metric dimensions, for example, the internals of pumps are almost invariably built to millimetre sizes.

Just as it is human to err, so too it is human to resent having to change one's habits, however great the advantages of the change, and therein lies the main obstacle, nonetheless real because of its abstract nature which, one and all, we the present generation of British mechanical engineers must make a determined effort to overcome, in order that our successors shall at least on this issue be on equal terms with their rivals. In other words, we must set aside those emotional reactions so stultifying to man's faculty of reason, and so often evoked upon his being faced with such a prospect, and allow our attitude to the problem of what can, and should be done, to be governed by clear reasoning, undistorted by such resentment. If we can thus bring ourselves to approach the problem with a truly open mind, we will find that a lot can be done with little, if any, even temporary inconvenience to our productive effort, towards making things easier for ourselves and our technical language understandable to the ever growing proportion of our customers overseas employing the metric units, whilst at the same time preparing the way for our, ultimately inevitable, adoption of the International M.K.S. System in its entirety.

As a first step we can discard all the redundant antiquated units relating to power and energy and retain only the international units, namely, the watt and the joule or their accepted multiples, already familiar to all of us now that electric power has practically everywhere replaced the old steam engine. What sense is there in thinking of power generated, power transmitted and power put into motors in kilowatts and then having to think of the power delivered by those motors to the machines they drive in horsepower. In deference to those who might at first believe themselves incapable of thinking in kilowatts in connection with mechanical plant, nameplates of motors and driven machines could, for the time being, easily be stamped with the equivalent horsepower figure under the kilowatt rating.

We should also join our colleagues, not only in electrical engineering, but now also in the aeronautical, steel making, chemical and many other branches of our own profession, in abandoning the outdated Fahrenheit scale of temperature. What sense is there in measuring temperatures in the reactors of nuclear power stations in degrees Centigrade, suddenly changing to degrees Fahrenheit for the steam to the turbines by which the heat energy from the reactors is transformed into power, and then back again to degrees Centigrade for temperatures in the electric generators? Invented by a German working in Holland, the Fahrenheit scale has long ago been dropped by Germany and Holland and, therefore, not even on sentimental grounds can any excuse be advanced for our trying to perpetuate that most impractical scale. Incidentally, such a step will actually facilitate matters for our instrument makers, who will thereby be relieved of the troublesome and costly necessity of catering for two different kinds of dials and charts.

With the abandonment of the Fahrenheit and Rankine scales, in favour of the International Centigrade and Kelvin scales for all purposes, we must, of course, also discard that hybrid creation the Btu, hitherto employed by us for measuring energy when in the form of heat. In doing so, we must be careful not to make the mistake of trying to replace it by the equally hybrid C.H.U., but go straight to the international unit, i.e. the joule, which in fact is already our basic standard for heat quantity measurements.* Work is now in hand for the preparation of a modern version of our Callendar Steam Tables and with the publication of this new version we shall have a golden opportunity of making a clean start with the international units of energy in all the applications of steam power engineering. If for the time being, we feel it necessary to refer the enthalpies and other properties of steam and water to the pound-mass, we shall at least have the advantage as in the M.K.S. system, that products of enthalpy drops in kJ/lb and mass flow rates in lb/s will give steam powers directly in kilowatts, i.e. in the same units we use to express the powers of the generators to which the turbines are coupled. Similarly, rates of heat energy ceded per unit time by bled steam to the feed water in heaters and by exhaust steam to circulating water will likewise be given directly in the same concise kW units by the products of the enthalpy differences in kJ/lb and the mass flow rates in lb/s.

It would, however, by far be preferable if all of us concerned with turbo machines would realise the advantages of going over directly to the international system, thereby dispensing with the remaining awkward conversion factors, for example in expressions such as those for the torque due to the rate change of angular momentum of the fluid in the stages of turbo-machinery and for velocity head energy, provided we are prepared to use in our calculations, kilogramme-mass units for our mass flows, the metre for lengths, and the

* Dr. Griffiths, " The Heat Unit," *Journal I.M.E.*, 1951, page 215.

bar for pressures as well as the joule for energy and the Centigrade scale for temperatures. Moreover, our new steam tables being completely in international units, would then be assured of widespread recognition abroad as well as at home. Whatever the basis of the tables, i.e. whether we retain temporarily the pound-mass, the foot and the pound-force, or whether we have the courage to go completely over to the international system, we must logically also employ the same units for energy relations in the associated steam boilers in conventional steam power plants as well as in nuclear reactors. If we feel we should for the time being retain our present units of mass, length and pressure, we shall here also still have the advantage of greatly simplified calculations and of much more concise expressions for units, for example units of rates of heat transfer and rates of heat liberation will become simply kW/ft^2 and kW/ft^3 respectively. In either case, throughout the cycle from calorific value of the fuel consumed to the energy delivered at the generator terminals, all quantities in the energy balance will be expressed directly and concisely in the same units.

Together with abandonment of the redundant units of energy and power and of the outdated Fahrenheit scale, we must ensure we use precise and exact mathematical notations for quantities still expressed in English units. We may, where appropriate, use the symbol W when we really mean weight, but when we mean mass, we must use the correct symbol m, and rid ourselves of the habit of irrelevantly referring to weights and writing W, for example, for the steam consumption of a turbine, or even, contrary to our conception of the physical dimensions of specific heat and enthalpy, in equations relating to heat quantities exchanged, which are no more dependent on the local intensity of gravity than the earlier example of the energy stored in a rotating flywheel. Similarly we must clearly distinguish the totally different physical characters of the units or force and mass, by the use of the abbreviations " lbf " and " lb " respectively, as recommended in the recently published additions to B.S.S. 1991 on " Letter Symbols, Signs and Abbreviations."

Above all, however, in our concern for the future of our profession, we must see that in all our schools and colleges our rising generations of engineers are educated in the use of the the new international units for mechanical as well as for electrical purposes. They have to be taught that system in their electrical courses and since it replaces the c.g.s. as well as the old electrical system, it is the obvious choice for use in teaching basic principles of all branches of physics. Moreover, there is no tenable reason why the system should not also be used in teaching the practical applied branches of mechanical engineering, especially those concerned with fluid-dynamics and thermo-dynamics. Lecturers and students alike will then no longer have to waste time in futile writing of conversion factors in equations, obscuring their physical content, and in the attendant wearisome arithmetical unit conversions. If and when graduates enter the industry old units are still being used in some branches, the clear thinking and precise methods acquired as a result of their tuition in M.K.S. units, far from being a hindrance, will enable them all the more readily to cope with any variety of either traditional English, or old metric units they might still encounter in their particular fields of activity.

Recent Express Train Running in France

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The electrification of certain sections of the Northern Region of the S.N.C.F. on the 25kV a.c. system at 50 cycles per second renders the train working of particular interest to British observers in view of the modernisation work now in progress on British Railways. At the same time the standards of performance regularly achieved with the earlier electrifications in France at 1500V d.c. are probably the highest anywhere in the world. The author describes some recent experiences with both systems of traction.

IT is no exaggeration to assert that the former Paris, Lyons and Mediterranean Railway, now the South Eastern Region of the S.N.C.F., is one of the fastest, if not the fastest, line in the world. What is remarkable, in view of the restrictions existing in some places elsewhere, is that little or no limit seems to be placed upon the loading of even the fastest trains. This winter, the " show " train of the line, " The Mistral," has been accelerated to make the run of 195·3 miles from Paris to Dijon in 138 min. —an average speed from start to stop of almost 85 m.p.h.—and yet the train is expected to load up to 700 tons or more, on occasions. Quite apart from the capacity of the locomotives employed, a factor that has contributed in very large measure towards making such fast services a practical proposition has been the elimination of all permanent speed restrictions between Paris and Lyons. Large and complicated junctions such as Melun, Montereau, and Laroche have had the through lines re-aligned to permit of unrestricted running at 90 m.p.h., and the high average speeds now scheduled can be maintained with a maximum of about 90 m.p.h. Coupled with this is a high standard of rolling stock maintenance, which provides very smooth, quiet, and restful travelling.

The locomotives employed on these fast services are of two types, the " CC7100 " class (Fig. 2), and the " BB9200." The leading characteristics of these extremely successful machines are shown in Table IV.

TABLE IV—*1500V D.C. Electric Locomotives: S.N.C.F. South-Eastern Region*

	C_0C_0	B_0B_0
Type		
Total weight (all available for adhesion)	106 tons	78½ tons
Length overall	62ft 1½in	53ft 2½in
Wheel diameter	4ft 1in	4ft 1in
Maximum service speed	99·3 m.p.h.	87 m.p.h.
Continuous rating at 1500V	4650 h.p.	4450 h.p.

While the " C " is dimensionally the more powerful, and has the advantage, in cases of exceptional loading, of a higher adhesive weight, the " BB " has proved a design of exceptional capability, and it can be said that the two types are now used indiscriminately on all the heaviest and fastest trains. The journeys to be described in this article were made in the course of ordinary travelling. The trains concerned were not the fastest over the routes concerned; they were chosen because they happened to fit in best with one's travelling programme, and can be taken as a typical cross-section of the kind of running that is now provided on the express trains of the South Eastern Region of the S.N.C.F.

Table V includes the logs of two non-stop runs between Paris and Dijon, both with the " BB " type locomotives. The gradients are undulating for the first 45 miles out of Paris, with a bank 7 miles long, mostly inclined at 1 in 250, immediately south of Villeneuve St. George. From Montereau southwards, however, the line is rising for 130 miles; very gradually at first, at such inclinations as 1 in 2000 and 1 in 2500, but becoming more pronounced after Laroche. After Tonnerre the average inclination becomes 1 in 400-500, and from Les Laumes real climbing begins, to culminate in 8 miles of which 6 miles are continuously at 1 in 125 to the summit at Blaisy Bas. From this point the descent into Dijon is mostly at 1 in 125. The two runs in Table V were made on express trains with booked average speeds of 78·7 and 70·3 m.p.h. respectively; both were very heavily loaded, though not exceptionally so, it should be added, by current French standards.

The evening train leaving Paris at 7.25 p.m., " L'Aquilon," serves only Dijon and Lyons, and it is interesting to find that at the time this run was made it was leaving Paris no more than 3 min. ahead of " The Simplon–Orient " express which had a schedule involving a start-to-stop average speed of 76·5 m.p.h. from Paris to Dijon. The Rome Express followed 25 min. later, with a rather slower timing of 66·5 m.p.h. On the journey shown in Table V " L'Aquilon," with a trailing load of 665 tons, ran

TABLE V—*S.N.C.F. South-Eastern Region: Paris–Dijon*

Train, ex Paris			7.25 p.m.		9.15 a.m.	
Locomotive No.			BB9254		BB9220	
Load, tons gross trailing			665		735	
Distance, miles			Time, min. sec.	Average speed, m.p.h.	Time, min. sec.	Average speed, m.p.h.
0·0	Paris (Lyon)		0 00	—	0 00	—
8·9	Villeneuve St. George		10 02	—	10 38	—
27·4	Melun		23 45	81·0	25 45	73·5
48·8	Montereau		38 43	85·8	42 15	77·8
78·9	Villeneuve-sur-Yonne		59 25	87·3	64 37	80·8
96·3	Laroche		71 25	87·2	78 35	74·7
107·1	St. Florentin		78 25	87·0	86 18	82·2
—			—	p.w. check	—	p.w. check
121·9	Tonnerre		89 10	86·3	100 26	62·8
—			p.w. check		—	
135·8	Ancy		112 10	39·8	114 01	61·5
159·6	Les Laumes		128 40	86·5	131 11	83·2
168·4	Thenissey		135 05	82·4	138 00	77·5
178·9	Blaisy Bas		142 50	81·5	146 58	70·2
195·3	Dijon		155 50	75·8	161 43	66·7
Net times (min.)			142½		154½	

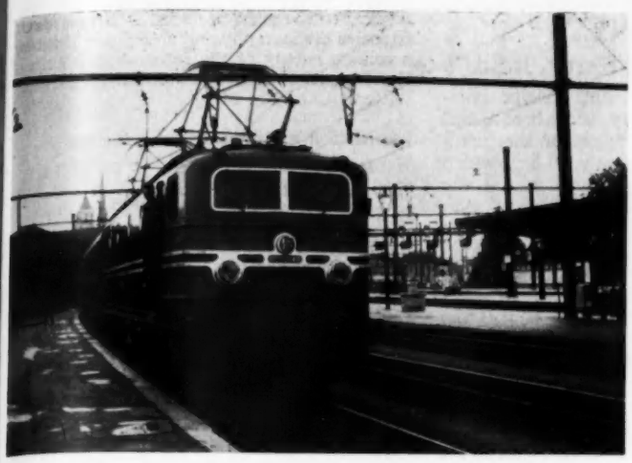

Fig. 2—1500V, "CC" type locomotive at Dijon

the 113 miles from Villeneuve St. George to Tonnerre in 79 min. 8 sec. at an average speed of 86 m.p.h., and the point-to-point averages show the very even speed maintained throughout. No maximum speed exceeding 90 m.p.h. was noted at any point. South of Tonnerre a long length of line under track repair caused some delay, and it will be convenient to take the earlier section of the second journey over the first 100 miles or so out of Paris. On the 9.15 a.m. the entire train goes through to Marseilles, with a restaurant car portion continuing along the Riviera coast to Ventimiglia. While supplementary fares are called for on "L'Aquilon," because of its high-speed schedules, the 9.15 a.m. requires no more than the standard fares, and is a very popular train in consequence. On the run tabulated the speed was not quite so even, though the average speed of 77·8 m.p.h. over the 98·2 miles from Villeneuve St. George to St. Florentin represented first-class locomotive work with a trailing load of 735 tons.

South of Tonnerre the work became very interesting on both runs. With "L'Aquilon" we were travelling at 87 m.p.h., immediately prior to the lengthy permanent way check, and speed was worked up to the same speed very soon after the end of the restricted length. The 13·9 miles from Tonnerre to Ancy actually took 23 min., while it can be assumed that with a continuation of the prevailing speed they would have occupied no more than 9¾ min. at the outside. The check cost 13 min. to 13½ min. on this basis of reckoning. Up the steepening gradients to Les Laumes speed continued at 86 to 87 m.p.h., while on the continuation to Thenissey on gradients averaging 1 in 220 well over 80 m.p.h. was sustained. Only on the final 4 miles, continuously at 1 in 125, did speed fall as low as 75 m.p.h. at Blaisy Bas summit. The very long check from Tonnerre had prevented overall time keeping, but with a fast run down into Dijon the journey was completed in 155¾ min.—an actual average speed of 75·3 m.p.h. and a net average of 82·4 m.p.h. from start to stop.

On the 9.15 a.m. from Paris the permanent way check between St. Florentin and Tonnerre was less severe; nevertheless, on account of it a stretch of 16½ miles took 19½ min., where the time would otherwise have been about 12½ min. Again the recovery uphill was very fine, and the maximum speed of the run was attained near Aisy, namely 88 m.p.h. As far up the final ascent as Thenissey speed was being held at 77 to 79 m.p.h., but on the easier schedule of this train time was well in hand, and speed was allowed to fall to 65 m.p.h. at Blaisy Bas. Elsewhere such a minimum speed, up 1 in 125 with a trailing load of 735 tons, would be considered outstanding; but the South Eastern Region of the S.N.C.F. has set its own standards and by these it was relatively easy work. A quiet run downhill to Dijon completed the run 5¾ min. ahead of time, while the net time, allowing for the Tonnerre check, showed an average speed of 75·7 m.p.h. start to stop—again very impressive work.

Southbound from Dijon further very fast running is called for over the 122·2 miles to Lyons. The journey was continued only on the morning train, and beside its schedule time of 104 min. start to stop may be set the 94 min. of "L'Aquilon," and the 92 min. of "The Mistral," even before the recent acceleration of this latter train. The very heavy night sleeping car expresses are mostly scheduled in 104 min. to 108 min. over this section. While there are numerous slight fluctuations in the gradients, up and down, the aggregate effect is dead level throughout, except for about 7 miles between Chagny and Chalon-sur-Saone, where the tendency is slightly downhill. Table VI shows the log of the running of the 9.15 a.m. from Paris on which almost exact time was kept from Dijon to Lyons, inclusive of a heavy slack for engineering work that cost about 7½ min. in running. From the log it will be seen that the general rate of progress was at 83 to 88 m.p.h. all the way until time was well in hand and the locomotive was eased after Villefranche. From Lyons to Valence the continuous and severe curvature of the line in the Rhone valley calls for restriction of the speed to 62 m.p.h. on certain stretches, and the overall average could not be so high; but the final section, to Avignon, again dead level on the average, gave a good spell of sustained high speed. The one locomotive worked through from Paris to Avignon, and it was handled by three different crews.

The concluding run was made on the 10.56 a.m. express from Turin to Paris, and on this service one locomotive of the "CC" type worked through, over the 370 miles from Chambery. By the attaching of through portions from various Alpine resorts this train gradually built up to a load of fifteen vehicles from Culoz—675 tons behind the locomotive; but over the curving stretches through mountain country no fast running can be made until one is out on to the plains, and past Amberieu. Then there was a characteristic French acceleration to a sustained 88 m.p.h. before slowing into Bourg. The log of the run northwards from this point is given in Table VII. The relatively short start-to-stop runs, to Macon, to Chalon-sur-Saone, and to Dijon were all smartly made, after which came the heavy ascent from Dijon to Blaisy Bas. This climb, 10 miles of which is graded at 1 in 125, was taken at a steady speed of 65 to 66 m.p.h. From this point northward, on favourable gradients, the speed was no more than that which had been run in the reverse direction with equally heavy trains. Again, as on the south bound journeys, the travelling was delightfully smooth and restful.

The impression gained by these journeys on the former P.L.M. system may perhaps be best epitomised by a recapitulation (as tabulated below) of the average speed from start to stop on the successive stages, all of these runs being made with loads of between 665 tons and 735 tons behind the locomotive.

TABLE VI—*S.N.C.F. South-Eastern Region. Dijon–Avignon*

Load: 18 vehicles, 735 tons gross, Locomotive "BB9220"

Distance miles		Time min. sec.	Average speed m.p.h.
0·0	Dijon	0 00	—
6·8	Gevrey Chambertin	8 12	—
13·9	Nuits St. George	13 01	88·5
22·9	Beaune	19 18	85·8
42·2	Chalon-sur-Saone	33 07	84·0
		p.w. check	
52·3	Sennecy	48 30	39·0
58·0	Tournus	52 51	78·6
77·9	Macon	66 35	87·1
101·1	Villefranche	82 55	85·3
		eased	
122·2	Lyon-Perrache	103 36	
0·0		0 00	
13·0	Chasse	13 23	—
22·4	Vangrishes	21 27	70·0
37·9	St. Rambert	32 51	81·6
54·8	Tain L'Hermitage	46 42	73·3
65·8	Valence	57 50	
0·0		0 00	
10·6	Livron	10 08	
27·3	Montelimar	21 53	85·3
59·6	Orange	47 00	76·9
68·6	Bedarrides	54 37	71·0
77·3	Avignon	64 37	

TABLE VII—*S.N.C.F. South-Eastern Region: Bourg–Paris*

Load: 15 vehicles, 675 tons gross, Locomotive "CC7125"

Distance, miles		Time, min. sec.	Average speed, m.p.h.
0·0	Bourg	0 00	—
5·0	Polliat	7 09	—
18·2	Pont de Velve	16 34	83·4
23·0	Macon	22 07	—
0·0		0 00	—
6·6	Senozan	7 37	—
30·6	Varennes	25 10	82·0
35·7	Chalon-sur-Saone	30 17	—
0·0		0 00	—
5·9	Fontaines	7 16	—
35·4	Gevrey Chambertin	29 45	78·7
42·2	Dijon	38 45	—
0·0		0 00	—
9·2	Lantenay	11 20	—
16·4	Blaisy Bas	17 56	65·5
35·7	Les Laumes	32 07	81·7
50·6	Aisy	46 23	62·7 (eased)
73·4	Tonnerre	62 39	84·3
93·7	Brienon	77 45	80·7
99·0	Laroche	83 01	—
0·0		0 00	—
5·9	Joigny	7 24	—
26·4	Sens	22 17	82·5
47·5	Montereau	38 54	76·4
68·9	Melun	57 28	77·5
87·4	Villeneuve St. George	74 28	65·3
		sig. check	
96·3	Paris–Lyon	88 38	—

Section	Distance, miles	Time (min.) Actual	Time (min.) Net	Net average speed, m.p.h.
Paris–Dijon	195·3	155½	142½	82·4
Paris–Dijon	195·3	161½	154½	75·7
Dijon–Lyons	122·2	103½	96	76·5
Lyons–Valence	65·8	57½	57½	68·3
Valence–Avignon	77·3	64½	64½	72·0
Bourg–Macon	23·0	22	22	62·7
Macon–Chalon	35·7	30½	30½	70·8
Chalon–Dijon	42·2	38½	38½	65·4
Dijon–Laroche	99·0	83	83	71·5
Laroche–Paris	96·3	88½	88½	65·1

Letter to the Editor

CENTRIFUGAL STRESSES IN A SINGLE WHEEL AND HUB

SIR,—With reference to the Technical Contribution by Mr. D. A. Thurgood on "Centrifugal Stresses in a Single Wheel and Hub," published in your issue of November 24, I feel that his proposals, although theoretically correct, do not give a full indication of the strength of a rotating disc. Mr. Thurgood suggests that when calculating the elastic stresses in a single wheel and hub, where the axial length of the hub is considerably greater than that of the wheel, one should consider the area of material cut off by a "diffusion angle" of 45 deg. drawn from the junction of the wheel and hub as imposing load without providing support.

The experimental evidence quoted may well be appropriate if one is concerned with elastic bore stress alone, but, I feel the principal concern of the designer is the state of stress under which the disc will come loose on the shaft and, finally, burst. It appears that the only satisfactory method of assessing this is by testing actual discs or scale models to destruction. Recent tests on scale models of a turbine disc of like profile with simulated blade loading have shown that the very high bore stresses calculated by the classical methods are rapidly dissipated into the surrounding elastic material once this bore stress reaches the elastic limit. The supposed region of highly stressed material is confined to a narrow band close to the bore surrounded by a large mass of material at a much lower stress level. Thus the degree of yielding at the bore necessary to redistribute the stress is extremely small; in fact, on test no measurable permanent deformation was apparent until the average tangential stress over the whole cross section became equal to the yield stress of the material.

Continuation of the tests to higher speeds produced a gradual radial growth of the discs until the average stress reached the ultimate strength of the material, at which point failure occurred. This evidence would suggest that once the elastic conditions at the bore are exceeded the whole cross section carries load. Furthermore, it suggests that the apparent high bore stresses obtained by elastic theory are not responsible for failure and that a better measure of the strength of a disc is the average tangential stress based on the complete cross-sectional area.

Further tests on models in cast iron showed that failure again occurred when the average stress equalled the ultimate strength of the material, whereas, since cast iron has a low ductility, one might have expected failure to occur as soon as the bore stress reached the ultimate. This confirms, therefore, that the degree of ductility necessary to redistribute the stress is small.

C. B. JENNINGS

Turbine Design Department,
C. A. Parsons and Co. Ltd.,
Newcastle upon Tyne,
December 15, 1961.

Obituary

Commander A. C. Hardy, B.Sc.

MANY naval architects and marine engineers, both in this country and abroad, will have learned with deep regret of the death of Commander A. C. Hardy, B.Sc., which occurred on Sunday, December 17, at the age of sixty-three years. Cecil Hardy, who received his shipbuilding training at Palmer's Shipbuilding and Iron Company, graduated from Durham University with a B.Sc.(Naval Architecture). After graduating he was associated with Camps and Co., the consulting naval architects, and then was technical editor of the *Marine Engineer* before going to America in 1925 to study United States shipbuilding and shipping. On his return to this country in 1928 he became senior partner in Hardy, Tobin and Co. Ltd. and during the war served as a constructor commander R.C.N.C. on the staff of Combined Operations. He also attended the first Quebec Conference as a technical adviser. Among many of his post-war activities can be numbered the founding of the International Cargo Handling Co-ordination Association, which is truly international in its scope and of which he was chief co-ordinator and technical President. Another of his interests was the development of the World Ship Society of which he was President for many years. Cecil Hardy travelled widely and had an encyclopaedic knowledge of ships and shipping and was a prolific author having many books to his credit and he also contributed a large number of articles to the technical press. He was a member and member of council of the Royal Institution of Naval Architects and the Institute of Marine Engineers, a member of the North East Coast Institution of Engineers and Shipbuilders and a Fellow of the Royal Geographical Society.

Books just published

New Thinking in School Mathematics

246 *pages. Tables.*

Publisher: Organisation for European Economic Co-operation. (Available in United Kingdom from H.M. Stationery Office.)

Price 15*s.*

This is a survey carried out by O.E.E.C. as part of their basic education programme, and surveys mathematics in schools in twenty member countries. The members submitted details of their individual teaching programmes, and the results were considered at the Royamont seminar held in 1959. This work collates the results of the seminar, and points out all the inadequacies of school mathematics teaching. The work offers a very strong case for sweeping reforms, and makes many suggestions. The volume also includes lists of delegates, member countries which answered the questionnaire, sample questions, and a bibliography.

[Reply Card No. 1463]

Convergence Problems of Orthogonal Series

350 *pages.*

Publisher: Pergamon Press Ltd.

by G. ALEXITS. Translated from the German by I. Földes.

Price 100*s.*

This is an enlarged and revised version of a German original giving a systematic account of the convergence theory and examining the actual state of the theory and summation of the general orthogonal series. Chapters included are fundamental ideas and examples of series of orthogonal functions, investigation of convergence behaviour of orthogonal series, Lebesgue functions, and classical convergence problems. There is also an extensive bibliography and an index. This book is volume twenty of the International Series of Monographs on Pure and Applied Mathematics.

[Reply Card No. 1464]

The Method of Mathematical Induction

57 *pages.*

Publisher: Pergamon Press Ltd.

by I. S. SOMINSKII.

Price 10*s.*

Fibonacci Numbers

66 *pages.*

Publisher: Pergamon Press Ltd.

by N. N. VOROB'EV.

Price 10*s.*

Some Applications of Mechanics to Mathematics

58 *pages. Diagrams.*

Publisher: Pergamon Press Ltd.

by V. A. USPENSKII.

Price 10*s.*

Geometrical Constructions using Compasses Only

78 *pages. Diagrams.*

Publisher: Pergamon Press Ltd.

by A. N. KOSTOVSKII.

Price 10*s.*

The Ruler in Geometrical Constructions

86 *pages. Diagrams.*

Publisher: Pergamon Press Ltd.

by S. A. SMOGORZHEVSKII.

Price 10*s.*

Inequalities

60 *pages.*

Publisher: Pergamon Press Ltd.

by P. P. KOROVKIN.

Price 10*s.*

These six books are the six volumes of a new Pergamon Press series entitled "Popular Lectures in Mathematics." The series is edited by I. N. Sneddon and M. Stark, and comprises original Russian works translated into English by Halina Moss. The series is meant primarily for use by students in secondary and high schools.

[Reply Card No. 1465]

Boundary Layer and Flow Control: Its Principles and Applications.

2 *volumes. Illustrations. Diagrams.*

Publisher: Pergamon Press Ltd.

Edited by G. V. LACHMANN.

Price £10 10*s. the set.*

These volumes are intended to cover the entire field of the subject, and are the collected contributions of many international authorities. The emphasis is on engineering applications, and a historical review of boundary layer research is included. Related subjects included are modern applications of the slot effect, jet flap, methods to prevent separation in transonic flow, and influence of boundary layer flow through geometric design. Each volume has a separate author and subject index.

[Reply Card No. 1466]

Control of Airborne Dust

479 *pages. Illustrations. Diagrams.*

Publisher: British Cast Iron Research Association, Alvechurch, Birmingham.

by W. D. BAMFORD, A.M.I.E.E., M.I.H.V.E.

Price £4 4*s.* (£3 5*s. to members of B.C.I.R.A.*)

Although the work described in this book is primarily directed at conditions prevailing in ironfoundries, it should be of interest and value in any industry where control of dust, fumes and air-flow has to be considered. Chapters include formation and dispersal of dust and fumes, thermal currents, design of dust exhaust systems, air movement and cross draughts, prediction of exhaust air volumes, sand cooling and dust control, control of dust-bearing air currents, importance of air cleaning, fans, practical application of design principles, and heating of workshops. There are six appendices and an index included in the volume.

[Reply Card No. 1467]

THE ENGINEER

TECHNICAL CONTRIBUTORS SECTION

DECEMBER, 1961

Behaviour of Reinforced Concrete Beams in Flexure

DEVELOPMENT OF A RATIONAL THEORY

By R. G. SMITH, B.Sc., A.M.I.C.E., A.M.I.Struct.E.,* and G. D. MATTHEW, B.Sc. (Eng.), A.M.I.C.E.*

The rational theory of reinforced concrete beams in flexure is based on a knowledge of the compressive stress/strain curve for concrete in flexure and of the stress/strain relationship of the mild steel reinforcement, together with certain generally accepted assumptions. It is shown that this leads to the conclusion that, for a specific beam, the moment of resistance M may be expressed as a unique function of the concrete strain in the top fibre, ϵ_c. Because of the nature of the concrete stress/strain curve this moment generally exhibits a maximum value, for which $dM/d\epsilon_c=0$. A critical review is given of the development of the theory, indicating that no single comprehensive treatment has yet appeared. This article attempts to illustrate in greater detail the trends in the relationships between the various parameters for beams of rectangular section. The particular case of a parabolic stress/strain curve for the concrete is selected as the simplest analytical form. It is shown that there are three distinct modes of behaviour depending on the steel percentage, namely under-reinforced, transition and over-reinforced. In the case of under and over-reinforced beams the criterion for a maximum moment is that $dM/d\epsilon_c=0$. In the transition zone, however, no stationary value exists, i.e. $dM/d\epsilon_c\neq0$ and the governing factor is that the steel strain is constant and equal to the yield strain. The limits of validity of the three modes in terms of steel percentage are established for typical properties of the concrete and steel. The concrete strain at failure for under-reinforced beams is shown to be a constant depending only on the shape of the concrete stress/strain curve. For transition and over-reinforced beams the ultimate concrete strain is a variable. The relationships between neutral axis depth, concrete strain, steel strain, bending moment and curvature are illustrated for beams with various steel percentages in the range from working load to failure.

1. Introduction

PRESENT-DAY design theories for the prediction of the ultimate moment of resistance of a reinforced concrete beam have been derived mainly from short term loading tests on beams of rectangular cross section. "Safe limiting values" at failure for the average concrete stress, position of the resultant compressive force above the neutral axis and the maximum concrete strain at failure are used. The ultimate load theories developed on this semi-empirical basis do not take into account, explicitly, the effect of rate of loading or the shape of the cross section. In addition they do not provide an accurate estimate of the behaviour of a beam for the range between working load and failure, an important factor in the plastic design of statically indeterminate reinforced concrete structures.

A rational theory, which elucidates all these factors, may be derived purely from a knowledge of the steel stress/strain curve and of the compressive stress/strain relationship for the concrete in flexure and by making certain generally accepted assumptions which will be stated later. The principal obstacle to the development of such a theory in the past has been the difficulty involved in the experimental determination of the complete stress/strain relationship for the concrete.

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2. Compressive Stress/Strain Relationships for Concrete

2.1. *Concentric Prism Tests.*—Concentric loading tests on concrete prisms in standard testing machines show that failure apparently occurs at a strain corresponding to the maximum stress. The sudden nature of these failures is due to the combined effects of the inertia and stiffness of the testing machine and its load measuring devices. It has been shown however,[1] that, if the testing machine is made sufficiently stiff and sensitive, it is possible to obtain much greater strains, the stress/strain curve exhibiting a "dropping-off" of the type shown in Fig. 1 (*a*).

More recently, Rüsch[2] and his colleagues have been able to obtain similar results by applying constant rates of strain to the specimens and have thus determined the effect of creep on the stress/strain relationships.

2.2. *Direct Beam Tests.*—The derivation of the stress/strain curves directly from beam tests is complicated by two principal factors :

(*a*) An analytical derivation,[3,4] (which ignores the effect of creep), has to be made from the experimental results. Such methods

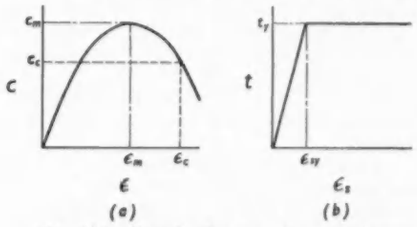


Fig. 1(*a*)—Stress/strain curve for concrete
Fig. 1(*b*)—Stress/strain relationship for steel

are strictly suitable for short term loading only.

(*b*) Failure of a beam tested in a standard testing machine occurs at the concrete strain corresponding to maximum moment in a similar fashion to concentric test failures in such a machine.

It will be shown later that the concrete strain at failure is a function of the beam shape, rate of loading (as reflected in the concrete stress/strain curve), stress/strain characteristics of the reinforcement and generally of the steel ratio. It is consequently difficult to obtain the complete stress/strain curve from ordinary beam tests.

2.3. *Simulated Beam Tests.*—Hognestad, Hanson and McHenry[5] have attempted to simulate the compression zone of a beam by devising an eccentrically loaded prism test with a strain gradient across the section, the strain at one face being maintained at zero. A modification of this method was also used by Smith.[6] This type of test is, strictly speaking, limited to short term loading, as the analytical derivation of the stress/strain curve again neglects the effect of creep.

2.4. *Application to Sections in Flexure.*—The stress/strain curves obtained by all of these investigators are roughly of the form shown in Fig. 1 (*a*), the exact shape depending on the concrete strength and on the applied

Technical Contributors Section (*Continued*)

rate of strain. In the absence of reliable data on the stress/strain relationship in the compression zone of beams the assumption is made that curves obtained from prism tests are of a similar nature. This hypothesis is subject to the reservation that there must be " good " bond between the reinforcement and the concrete. Smith[7] has shown that, in the case of " poor " bond, there is a concentration of strain in the concrete above the flexural cracks, the ultimate strain having a greater value than found from a prism test.

3. Basic Assumptions and Scope of Theory

3.1. *Assumptions.*—The assumptions which form the basis of the present treatment and of most of the recent publications on the ultimate flexural strength of reinforced concrete beams are as follows :

(*a*) The concrete compressive stress/strain curve is of the general form shown in Fig. 1 (*a*), the exact shape being a function of the concrete strength and rate of straining ;

(*b*) the tensile strength of the concrete may be neglected ;

(*c*) The steel stress/strain relationship is of the conventionally accepted form for mild steel shown in Fig. 1 (*b*) ;

(*d*) The strain in the reinforcement is equal to the strain in the adjacent concrete i.e. bond is " good " ;

(*e*) Plane sections remain plane.

3.2. *Scope of Theory.*—The theory enables estimates to be made of :

(*a*) The position of the neutral axis, strains in the concrete and reinforcement, and the moment-curvature relationship for a specific beam in the range from working load to failure ;

(*b*) The effect of beam shape, dimensions and steel ratio on the above parameters at failure ;

(*c*) The effect of rate of loading, by using the various stress/strain curves for concrete obtained experimentally taking creep into account.

4. Review of Previous Work

The first paper to be published in English, which provided a correct interpretation on the basis of the assumptions set out in Section 3.1 was apparently that of Lee.[8] He based his analysis on a parabolic stress/strain curve for the concrete, but, in evaluating the maximum flexural resistance of the section, he used the approximation that $dM/d\chi=0$, where χ is the curvature. The limits of validity of the resulting formulae were not defined.

The most complete treatment of the theory, at the time of writing, has been given by Ali,[9] who used a concrete stress/strain curve of the form $c/c_m=(\epsilon/\epsilon_m)exp(1-\epsilon/\epsilon_m)$. This appears to be the only paper which has drawn attention to the existence of a " transition zone " between the under and over-reinforced cases. There is no specific description, however, of the relationships between the parameters in the range from working load to failure. Kriz[10,11] used an analytical function to approximate to the experimental stress/strain curves obtained by Hognestad, Hanson and McHenry, and obtained his results numerically. The relationship between the ultimate moment and steel percentage was shown, but the limits of validity were not established. Young[12] assumed three analytical expressions for the concrete stress/strain curve. Unfortunately, however, he assumed that the neutral axis depth was independent of the concrete strain and also made an erroneous derivation of the maximum moment of the compressive stress block about the neutral axis. Rüsch[2] used the stress/strain curves obtained from his prism tests, which take time effects into account. He also wrongly assumed the neutral axis depth to be independent of the concrete strain. Pointing this out in the subsequent discussion, Kriz[13] showed that this leads to approximately correct values for the ultimate moment, but larger errors in the other parameters. Rüsch also showed, by considering the effect of the applied rate of strain on the shape of the concrete stress/strain curve, that there was a critical rate of loading for which the ultimate moment of a specific beam was a minimum. Mattock and Kriz[14] have recently extended the earlier work of Kriz to the cases of triangular and " L " sections. They have concentrated attention on the variation of neutral axis position and concrete strain with moment, illustrating this by comparison between theoretical and experimental values for specific beams from each category. In view of the history of the development of the theory it seems timely to present a unified treatment which attempts to illustrate all its aspects.

5. General Theory for Rectangular Beams

5.1 *General Equations.*—To avoid unnecessary complexity the analysis is confined to beams of rectangular section although the same broad principles apply to beams of any shape. The symbols used throughout are defined in the Appendix.

Consider a beam of rectangular cross section as shown in Fig. 2 (*a*), with mild steel reinforcement having the stress/strain characteristics shown in Fig. 1 (*b*). The concrete compressive stress/strain relationship for a prescribed rate of straining is given by the function

$$c=F(\varepsilon) \quad . . . . . (1)$$

Referring to the strain diagram, Fig. 2 (*b*),

$$y=\frac{nd}{\varepsilon_c}\varepsilon \quad . . . . . (2)$$

For equilibrium normal to the section,

$$A_st=\int_0^{nd} cbdy \quad . . . . . (3)$$

or, changing the independent variable to ϵ by means of (2),

$$A_st=\frac{bnd}{\varepsilon_c}\int_0^{\varepsilon_s} F(\varepsilon)d\varepsilon=\frac{bnd}{\varepsilon_c}I_1(\varepsilon_c) \quad . . . (3a)$$

where

$$I_1(\varepsilon_c)=\int_0^{\varepsilon_s} F(\varepsilon)\,d\varepsilon \quad . . . . . (4)$$

hence

$$n=\frac{pt\varepsilon_c}{I_1(\varepsilon_c)} \quad . . . . . (5)$$

The moment of resistance at the section is given by

$$M=A_st(1-n)d+\int_0^{nd} cby\,dy \quad . . . (6)$$

Again changing the independent variable to ϵ and dividing throughout by bd^2,

$$\frac{M}{bd^2}=\frac{A_st}{bd}(1-n)+\frac{n^2}{\varepsilon_c^2}\int_0^{\varepsilon_s} F(\varepsilon)d\varepsilon \quad . . . (6a)$$

$$=pt(1-n)+\frac{n^2}{\varepsilon_c^2}I_2(\varepsilon_c) \quad . . . . (6b)$$

where the steel ratio

$$p=A_s/bd \quad . . . . . (7)$$

and

$$I_2(\varepsilon_c)=\int_0^{\varepsilon_s} F(\varepsilon)\varepsilon d\varepsilon \quad . . . . . (8)$$

Substituting for n from (5),

$$\frac{M}{bd^2}=(pt)-(pt)^2\frac{[\varepsilon_cI_1(\varepsilon_c)-I_2(\varepsilon_c)]}{I_1^2(\varepsilon_c)} \quad . . (9)$$

As the relationship between steel stress and strain is discontinuous as shown in Fig. 1 (*b*), it is necessary to consider two cases, namely when $\epsilon_s \leqslant \epsilon_{sy}$ and when $\epsilon_s \geqslant \epsilon_{sy}$.

Case [*A*] $\epsilon_s < \epsilon_{sy}$.

From the strain diagram, Fig. 2 (*b*),

$$\frac{\varepsilon_c}{\varepsilon_s}=\frac{1-n}{n} \quad . . . . . (10)$$

$$\therefore t=\frac{E_s(1-n)}{n}\varepsilon_c \quad . . . . . (11)$$

Substituting for n from Equation (5) and solving the resulting quadratic

$$t=\frac{E_s}{2}\left[-\varepsilon_c+\sqrt{\varepsilon_c^2+\frac{4I_1}{pE_s}}\right] \quad . . (12)$$

the positive root being necessarily taken.

Case [*B*] $\epsilon_s \geqslant \epsilon_{sy}$.

In this case, throughout the range,

$$t=t_y \quad . . . . . (13)$$

Hence it will be noted that for both cases [*A*] and [*B*], it is possible to express M/bd^2 from Equation (9) as a function of ϵ_c alone for a specific steel ratio p.

Quite generally, the curvature of the neutral axis of the beam is given by

$$\chi=\frac{\varepsilon_c}{nd} \quad . . . . . (14)$$

It must be emphasised that all the previous equations are valid throughout the range from working load to failure.

5.2. *Maximum Moment of Resistance.*—For practical purposes the ultimate or failure moment of resistance of the section will occur when M/bd^2 from (9) and (12) or (9) and (13), whichever is appropriate, takes its maximum

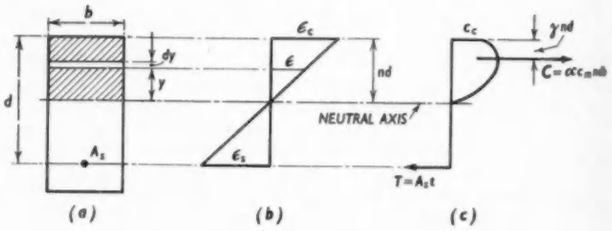


Fig 2(*a*)—Cross section
Fig. 2(*b*)—Strains
Fig. 2(*c*)—Stresses

value, i.e. when $dM/d\epsilon_c=0$. Let the maximum concrete strain at which this occurs be given by $\epsilon_c=\epsilon_u$. The solution of the equation

$$\left(\frac{dM}{d\epsilon_c}\right)_{\epsilon_c=\epsilon_u}=0 \quad . \quad . \quad (15)$$

enables ϵ_u to be determined and, by substituting this value in the relevant equations, the values of the other parameters at failure may be found.

These equations cannot be solved explicitly in general terms, but some interesting conclusions will be drawn presently for the case of under-reinforced rectangular beams.

It will be shown later that there is in fact a range of values of steel percentage for which a stationary value on the $M/bd^2-\epsilon_c$ curve cannot exist. The zone in which this occurs has been termed the " transition zone " and the mode of failure " transition failure."

(It may be noted in passing that the analysis presented in this section is the converse of that of Prentis[3] for the determination of the stress/strain curve for concrete from a beam test).

5.3. *Under-Reinforced Rectangular Beams.*—Let ϵ_{su} be the steel strain corresponding to the concrete strain ϵ_u.

Then $\epsilon_{su}>\epsilon_{sy}$ and $t=t_y$ throughout.

(i) Condition for maximum moment.

Substituting $t=t_y$ in Equation (9), differentiating with respect to ϵ_c and setting $(dM/d\epsilon_c)_{\epsilon_c=\epsilon_u}=0$.

$$2\epsilon_u F(\epsilon_u)I_1(\epsilon_u)-2F(\epsilon_u)I_2(\epsilon_u)-I_1^2(\epsilon_u)=0 \quad . \quad . \quad . \quad (16)$$

It will be noted that the solution of this equation for ϵ_u depends only on the form of the function $F(\epsilon)$ i.e.

The ultimate concrete strain at failure of an under-reinforced rectangular beam is a constant whose value depends only on the form of the stress/strain curve for the concrete.

This is in accordance with the existing semi-empirical design theories.

(ii) Limits of validity.

The section is " under-reinforced " provided $\epsilon_{su}\geqslant\epsilon_{sy}$. Hence from Equation (10)

$$\frac{(1-n)}{n}\epsilon_u\geqslant\epsilon_{sy} \quad . \quad . \quad . \quad . \quad (17)$$

$$n\leqslant\frac{\epsilon_u}{\epsilon_{sy}+\epsilon_u} \quad . \quad . \quad (17a)$$

Substituting this inequality in Equation (5) the limits of validity for an under-reinforced beam are :

$$0<p<\frac{\int_0^{\epsilon_u}F(\epsilon)d\epsilon}{t_y(\epsilon_{sy}+\epsilon_u)} \quad . \quad . \quad . \quad (18)$$

where ϵ_u is a constant.

6. Particular Solution for a Parabolic Concrete Stress/Strain Curve

6.1. *General Relationships.*—As it is the purpose of this article to illustrate only the general trends of the relationships between the parameters, a concrete stress/strain curve having a simple parabolic form has been assumed. Similar analysis may be made for experimentally determined stress/strain curves by numerical methods. Here then,

$$c=F(\epsilon)=c_m\left[2\left(\frac{\epsilon}{\epsilon_m}\right)-\left(\frac{\epsilon}{\epsilon_m}\right)^2\right] \quad . \quad . \quad (19)$$

Therefore

$$I_1(\epsilon_c)=\int_0^{\epsilon_c}F(\epsilon)d\epsilon=c_m\epsilon_c\left[\left(\frac{\epsilon_c}{\epsilon_m}\right)-\frac{1}{3}\left(\frac{\epsilon_c}{\epsilon_m}\right)^2\right] \quad . \quad . \quad . \quad . \quad . \quad (20)$$

and

$$I_2(\epsilon_c)=\int_0^{\epsilon_c}F(\epsilon)\epsilon d\epsilon=c_m\epsilon_c^2\left[\frac{2}{3}\left(\frac{\epsilon_c}{\epsilon_m}\right)-\frac{1}{4}\left(\frac{\epsilon_c}{\epsilon_m}\right)^2\right] \quad . \quad . \quad . \quad . \quad (21)$$

Substituting these expressions in (5) and (9)

$$n=\frac{pt}{c_m\left[\left(\frac{\epsilon_c}{\epsilon_m}\right)-\frac{1}{3}\left(\frac{\epsilon_c}{\epsilon_m}\right)^2\right]} \quad . \quad . \quad . \quad . \quad (5a)$$

and

$$\frac{M}{bd^2c_m}=\left(\frac{pt}{c_m}\right)-\left(\frac{pt}{c_m}\right)^2\frac{\left[\frac{1}{3}\left(\frac{\epsilon_c}{\epsilon_m}\right)-\frac{1}{12}\left(\frac{\epsilon_c}{\epsilon_m}\right)^2\right]}{\left[\left(\frac{\epsilon_c}{\epsilon_m}\right)-\frac{1}{3}\left(\frac{\epsilon_c}{\epsilon_m}\right)^2\right]} \quad . \quad . \quad . \quad . \quad (9a)$$

6.2. *Under-Reinforced Beams.*—Substituting $t=t_y$ in Equation (9*a*), differentiating and setting $(dM/d\epsilon_c)_{\epsilon_c=\epsilon_u}=0$, the condition for maximum is found to be

$$\left(\frac{\epsilon_u}{\epsilon_m}\right)^2-6\left(\frac{\epsilon_u}{\epsilon_m}\right)+6=0$$

Extracting the physically relevant root,

$$\epsilon_u=(3-\sqrt{3})\epsilon_m=1\cdot268\epsilon_m \quad . \quad (22)$$

Substituting (22) in (9*a*) and simplifying

$$\frac{M_u}{bd^2c_m}=\frac{pt_y}{c_m}\left[1-\frac{(3+2\sqrt{3})}{12}\frac{pt_y}{c_m}\right]=\frac{pt_y}{c_m}\left[1-0\cdot539\frac{pt_y}{c_m}\right] \quad . \quad (23)$$

Substituting the following typical values in Equations (20) and (18), namely $c_m=3000$ lb per square inch, $\epsilon_m=0\cdot002$, $t_y=40{,}000$ lb per square inch, $E_s=30\times10^6$ lb per square inch, the limits of validity of the under-reinforced range of steel ratios becomes

$$0<100p<3\cdot60 \text{ per cent}$$

In the range from working load to failure the values of M, n, ϵ_s and χ may be obtained for values of $\epsilon_c<\epsilon_u$ by substituting into the appropriate equations. It should be noted that the steel strains will be in the elastic range at working load increasing to values greater than the yield strain at failure.

6.3. *Over-Reinforced Beams.*—Here $\epsilon_{su}\leqslant\epsilon_{sy}$ or $t\leqslant t_y$. Substituting for t from Equation (11) in Equation (5*a*),

$$n=\frac{pE_s(1-n)\epsilon_c}{nc_m\left[\left(\frac{\epsilon_c}{\epsilon_m}\right)-\frac{1}{3}\left(\frac{\epsilon_c}{\epsilon_m}\right)^2\right]}$$

$$\therefore \quad \frac{\epsilon_c}{\epsilon_m}=3\left[1-\frac{\theta(1-n)}{n^2}\right] \quad . \quad . \quad . \quad (24)$$

where

$$\theta=\frac{pE_s\epsilon_m}{c_m} \quad . \quad . \quad . \quad (25)$$

Substituting for (ϵ_c/ϵ_m) and t from Equations (24) and (11) respectively in Equation (9*a*),

$$\frac{M}{bd^2c_m}=\frac{(n^2-\theta+\theta n)(12\theta-15\theta n+3\theta n^2-n^3)}{4n^3} \quad . \quad . \quad . \quad (26)$$

It will be noted that it has been found more convenient to express (M/bd^2c_m) as a function of n rather than of ϵ_c.

The condition for maximum moment is now therefore $dM/dn=0$. Hence differentiating (26) with respect to n, setting $dM/dn=0$ and simplifying,

$$-n^5+\theta n^4-3(2\theta-3\theta^2)n^3-27\theta^2n+18\theta^2=0 \quad . \quad . \quad . \quad . \quad (27)$$

The equation may be solved more readily by re-arranging in the form :

$$\theta^2+\left(\frac{n^4-6n^3}{\lambda}\right)\theta-\frac{n^5}{\lambda}=0$$

where

$$\lambda=9n^2-27n+18$$

The relevant root of the quadratic is

$$\theta=\frac{6n^3-n^4+n^2\sqrt{(n^2-6)^2+4n\lambda}}{2\lambda} \quad . \quad . \quad (28)$$

Hence for any value of $\theta=pE_s\epsilon_m/c_m$, the value of n for maximum moment may be obtained. Equations (24) and (26) then enable the corresponding values of (M/bd^2c_m) and ϵ_u to be determined. It will be observed that ϵ_u cannot be a constant but is a function of the parameter 0.

6.4. *Limits of Validity for Over-Reinforced Beams.*—The section is over-reinforced as long as $\epsilon_{su}\leqslant\epsilon_{sy}$, i.e. making use of Equation (10),

$$\frac{(1-n)}{n}\epsilon_u\leqslant\epsilon_{sy}$$

Substituting for ϵ_u from Equation (24) and simplifying

$$\theta>\frac{n^2}{(1-n)}\left[1-\frac{n}{3(1-n)}\frac{\epsilon_{sy}}{\epsilon_m}\right] \quad . \quad (29)$$

That is, from Equation (28)

$$\frac{6n^3-n^4+n^2\sqrt{(n^2-6)^2+4n\lambda}}{2\lambda}>\frac{n^2}{(1-n)}\left[1-\frac{n}{3(1-n)}\frac{\epsilon_{sy}}{\epsilon_m}\right] \quad . \quad . \quad . \quad (30)$$

The solution of this inequality for the numerical values of ϵ_{sy} and ϵ_m already assumed in Section 6.2 is $n>0\cdot69$. The corresponding values of p and ϵ_u are obtained by substituting in Equations (28) and (24) respectively, whence $p>3\cdot88$ per cent and $\epsilon_u\leqslant0\cdot298$ per cent. The equal signs will apply when the steel strain is just equal to ϵ_{sy}.

In the range between working load and failure the values of M, ϵ_c, &c. for a specific beam may be found by substituting values of n in Equations (26), (24), &c.

6.5. *Transition Failure.*—It will be seen from the above discussion that in the range $3\cdot60$ per cent $<p<3\cdot88$ per cent, neither the under-reinforced nor over-reinforced cases are valid, although the steel strain at their limits of validity is, in each case, the yield strain of ϵ_{sy}. Thus in this range of steel percentages, the steel strain at failure must be equal to ϵ_{sy}. In this " transition zone " there can be no stationary value on the $M-\epsilon_c$ curve, i.e. $dM/d\epsilon_c\neq0$ at failure.

The relationship between steel and concrete strains at failure is given by Equation (10)

$$\therefore \quad \epsilon_u=\frac{n}{1-n}\cdot\epsilon_{sy} \quad . \quad . \quad . \quad (31)$$

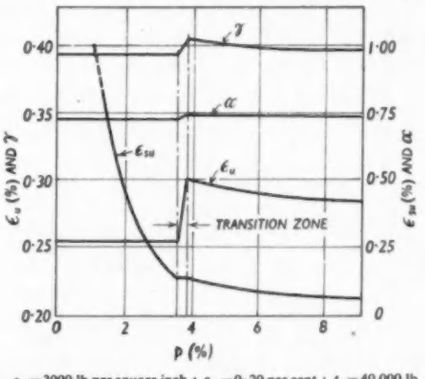
Substituting (31) in Equation (5*a*)

$$\frac{pt_y}{c_m}=n\left[\frac{n}{(1-n)}\frac{\epsilon_{sy}}{\epsilon_m}-\frac{1}{3}\frac{n^2}{(1-n)^2}\left(\frac{\epsilon_{sy}}{\epsilon_m}\right)^2\right] \quad (32)$$

Equations (31), (32) and (9*a*) enable the values of ϵ_{sy}/ϵ_m, pt_y/c_m and finally M/bd^2c_m to be calculated for any value of n.

6.6. Discussion of Results

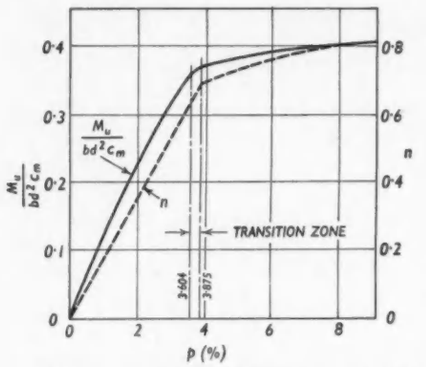
(i) *Failure Conditions.*—Perhaps the most significant feature of the theory is its illustration of the variation of the ultimate concrete strain with steel percentage. This is shown in Fig. 3, where it can be seen that in the transition zone there is a rapid increase of ϵ_u with p,



$c_m=3000$ lb per square inch ; $\epsilon_m=0\cdot20$ per cent ; $t_y=40{,}000$ lb per square inch ; $E_s=30\times10^6$ lb per square inch.

Fig. 3—Variation of steel and concrete strains, α and γ with steel percentage at failure

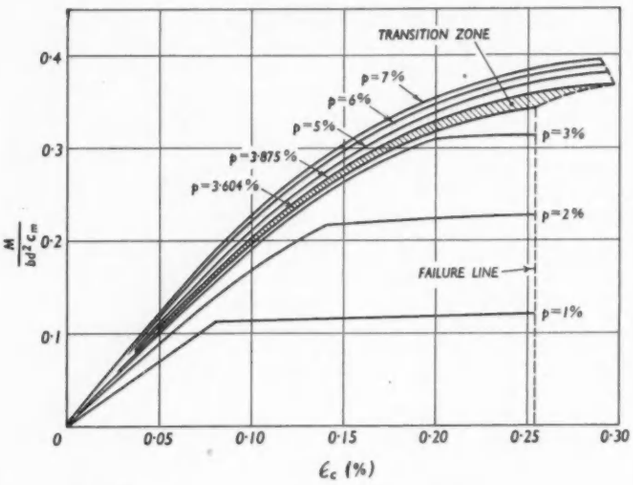
Technical Contributors Section (*Continued*)



c_m = 3000 lb per square inch ; ϵ_m = 0·20 per cent ; f_y = 40,000 lb per square inch ; $E_s = 30 \times 10^6$ lb per square inch.

Fig. 4—The variation of ultimate moment and position of the neutral axis at failure with steel percentage

reaching a maximum at the limit of validity of the over-reinforced case. For higher values of p there is a slow decrease from this maximum value.



c_m = 3000 lb per square inch; ϵ_m = 0·20 per cent ; f_y = 40,000 lb per square inch ; $E_s = 30 \times 10^6$ lb per square inch.

Fig. 5—Variation of moment of resistance with concrete strain for various steel percentages

The steel strain at failure, ϵ_{su}, is also shown in Fig. 3, which illustrates its constant value, equal to ϵ_{sy}, in the transition zone. It may also be observed from this figure that α and γ are constant for under-reinforced beams, with a slight increase in the transition zone in sympathy with that occurring in the ultimate concrete strain.

The relationships between (M_u/bd^2c_m) and n with steel percentage are shown in Fig. 4. Here there are no marked discontinuities in the transition zone.

(ii) *Working Load to Failure.*—Fig. 5 shows the relationship between (M/bd^2c_m) and ϵ_c for various values of p, as the section is loaded from working load to failure. The curves terminate on the "failure line," their values at the intersection corresponding to maximum moment.

The moment-curvature relationships are shown in Fig. 6. It may be seen that with low steel percentages the section is "ductile" with a relatively large capacity for rotation. As the steel percentage is increased the section becomes "brittle," with a considerable discontinuity in the transition zone.

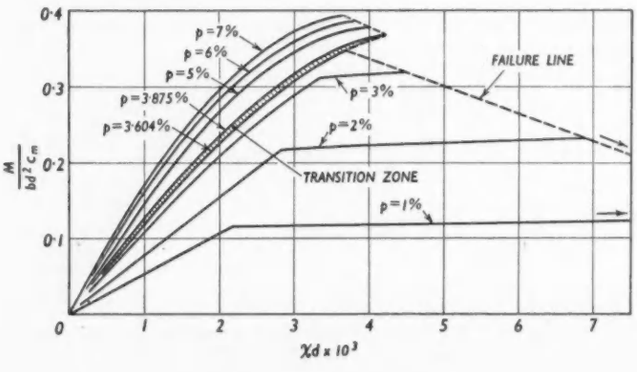
Another interesting feature of the theory is illustrated in Fig. 7 which shows the relationship between n and ϵ_c during a loading test. The principal feature here is that as long as the steel strain is less than the yield strain, the neutral axis depth increases. As soon as the steel strain becomes greater than the yield strain the neutral axis depth starts to decrease.

Thus the neutral axis depth in under-reinforced beams increases initially until the yield strain is reached and subsequently decreases with further loading, whereas for over-reinforced beams the neutral axis depth increases continuously to failure.

7. Conclusions

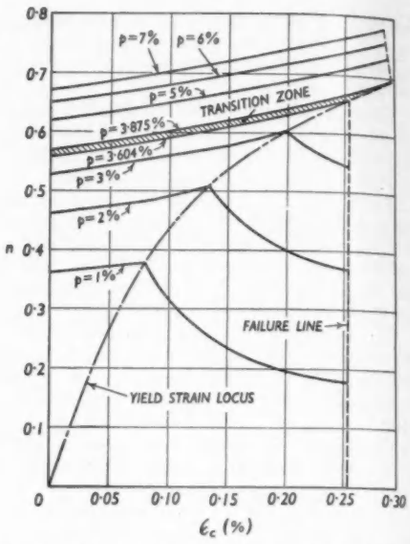
7.1. An overall picture of the relationships between the parameters has been obtained using a parabolic stress/strain curve for the concrete. Similar trends will occur with other forms of the stress/strain relationship. The results of the theory may be conveniently subdivided into behaviour at failure and at intermediate loadings respectively.

7.2. *Failure Characteristics.*—It has been shown that a rectangular concrete section in flexure, reinforced with mild steel, has three distinct modes of behaviour depending on steel percentage, namely under-reinforced, transition and over-reinforced.



c_m = 3000 lb per square inch; ϵ_m = 0·20 per cent ; f_y = 40,000 lb per square inch ; $E_s = 30 \times 10^6$ lb per square inch.

Fig. 6—Moment/curvature relationship for various steel percentages



c_m = 3000 lb per square inch ; ϵ_m = 0·20 per cent ; f_y = 40,000 lb per square inch ; $E_s = 30 \times 10^6$ lb per square inch.

Fig. 7—The variation of neutral axis position with concrete strain for various steel percentages

In the case of under-reinforced sections at failure, the steel strain is greater than the yield strain and $dM/d\epsilon_c = 0$. In general, for any specific stress/strain curve of the concrete, the ultimate concrete strain and the values of α and γ are constant for all values of steel percentage within the limits of validity. This is in accordance with the existing design theories.

Within the transition zone the steel strain at failure is equal to the yield strain and $dM/d\epsilon_c \neq 0$. The values of steel percentage in this phase are intermediate to those at the limits of validity of the under and over-reinforced beams. The ultimate concrete strain is not constant, its value increasing rapidly as the steel percentage is increased, reaching a maximum at the limit of validity of the over-reinforced phase.

In the case of over-reinforced sections at failure, the steel strain is less than the yield strain and $dM/d\epsilon_c = 0$. The ultimate concrete strain is not constant, its value decreasing slowly as the steel percentage is increased. The variation in the values of α and γ is slight for the parabolic stress/strain curve of the concrete adopted in the analysis.

The above conclusions are based on the use of mild steel reinforcement which exhibits a horizontal portion on the stress/strain curve corresponding to yielding of the steel. If the reinforcement has no definite yield zone of this type, then the ultimate concrete strain will vary for all values of the reinforcement percentage. It may also be deduced that the ultimate concrete strain depends on the shape of the cross section of the beam.

7.3. *Intermediate Loading Characteristics.*—For any specific beam, as long as the steel strain is in the elastic region, the neutral axis depth increases with the applied moment. When the steel strain reaches values greater than the yield strain the neutral axis depth decreases with further increments of load. Thus for under-reinforced beams the neutral axis depth increases at low loads until the yield strain is attained and then decreases as failure is approached. In the case of beams which have steel percentages in the transition or over-reinforced phases, the steel strain is

always less than the yield strain and hence the neutral axis depth increases throughout.

The theory also enables the moment/curvature relationships to be established, a knowledge of which is necessary in the plastic design of statically indeterminate structures. The results illustrate the typical " brittleness " of over-reinforced sections in comparison with the relative " ductility " of under-reinforced sections with low steel percentages.

7.4. *Time Effects.*—As Rüsch[2] has shown, an important aspect of the theory is its elucidation of the effects of creep on the behaviour of the beams. This may be ascertained by the use of the various stress/strain curves of the concrete obtained experimentally by subjecting prisms to various rates of strain. Thus the critical rate of strain for which the section will have the least moment of resistance may be determined.

7.5. The future application of the theory for design purposes must be based on actual stress/strain curves for concrete obtained at the critical rate of strain. The results may be expressed conveniently in graphical form of a similar nature to those shown in this article. However, further research on the stress/strain curves of concrete in flexure is desirable, particularly results derived from beam tests where the effects of cracking and strain gradient may be significant.

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APPENDIX

List of Symbols

b—Breadth of rectangular beam.
d—Effective depth to tensile reinforcement.
nd—Depth of neutral axis.
γnd—Depth from top fibre to resultant compressive force.
y—Distance measured from neutral axis.
A_s—Area of steel tensile reinforcement.
$p = A_s/bd$—Steel ratio.
E_s—Modulus of elasticity of steel reinforcement
M—Moment of resistance.
M_u—Ultimate moment of resistance.
ε—Strain in concrete.
ε_m—Strain in concrete corresponding to maximum stress.
ε_c—Strain in concrete in top fibre.
ε_u—Strain in concrete in top fibre at failure.
ε_s—Strain in steel reinforcement.
ε_{sy}—Yield strain of steel.
ε_{su}—Strain in reinforcement at failure.
$c = F(\varepsilon)$—Compressive concrete stress.
c_m—Maximum compressive concrete stress.
αc_m—Average concrete stress over compression zone.
t—Tensile stress in reinforcement.
t_y—Yield stress of steel.

$I_1(\varepsilon_s) = \int_0^{\varepsilon_s} F(\varepsilon)\,d\varepsilon$—A defined function.

$I_2(\varepsilon_s) = \int_0^{\varepsilon_s} F(\varepsilon)\varepsilon\,d\varepsilon$—A defined function.

$\chi = \varepsilon_s/nd$—Curvature of neutral axis of beam.
$\theta = pE_s\varepsilon_m/c_m$—A parameter.
$\lambda = 9n^3 - 27n + 18$—A defined function.

Hydrodynamic and Hydromagnetic Shock Waves in Controlled Thermonuclear Fusion

By DR. M. McCHESNEY

This article deals with the physical principles describing the shock wave that arises when a thermonuclear pinched discharge is created. Distinction is made between two kinds of shock wave, namely, the hydrodynamic case where no magnetic field is involved and the hydromagnetic case when the shock wave propagates into a gas containing a magnetic field. The limitations of the former for heating the gas are discussed and the unusual features and problems of the latter are indicated.

MUCH of the British effort, until quite recently, to produce thermonuclear reactions in a gas has utilised the " pinch " discharge as a method of producing and containing the hot plasma.[1] A " pinch " discharge is obtained by connecting a charged capacitor bank to the low-pressure gas such that the initial rate of rise of current through the gas is sufficiently high that skin effect causes the current to flow at the interface between the gas and the containing vessel rather than through the gas as a whole. This cylindrical current sheet produces a magnetic field normal to it (the " self " field) and by the " Left Hand " rule there will be a force on the conductor normal to both current and magnetic field. This force causes the current sheet to move radially inwards, i.e. collapse, and so form a " pinch."

There are two families of pinch discharge. If we take cylindrical co-ordinates, r, θ, z then if the current i flows in the z direction, i.e. axial, then the magnetic field B will be in the θ direction, i.e. azimuthal, so that there will be a force of magnitude $i_z B_\theta$ acting in the radially inwards direction ; this is known as a z pinch because the current flows in the z direction. Examples are " Oswald " and " Columbus " which are z pinches between electrodes in straight tubes and " Zeta," " Sceptre," " Perhapsatron " which are toroidal z pinches produced inductively.[2,3] If, however, the current flows in the θ direction, i.e. azimuthally, then the magnetic field will be in the axial z direction and once again we get an inward radial force, this time of magnitude $i_\theta B_z$. Such θ pinches are always produced inductively ; examples are " Scylla," " Thetatron."[4]

It is the collapse of this skin current sheet that is the topic under extensive investigation nowadays. The reason is that the gas enclosed by the collapsing current sheet may be swept up in the implosion and compressed at the axis of the containing vessel. As work is done during this compression the temperature of the gas will be raised as well as the density and it is, in principle, possible to raise the gas to the extremely high temperatures required to obtain significant thermonuclear reactions.

In the pinched discharge the approach to these thermonuclear temperatures and densities can be envisaged as taking place in three stages, although these are not always separated in time. A typical (and perhaps rather ideal) sequence of events is as follows. Stage 1 starts with a cold gas at room temperature to which a radio-frequency electric field is applied (pre-ionisation or " pre-heat "). This electric field feeds energy to any stray electrons in the gas such as will always exist due to cosmic radiation and these energetic electrons in turn produce further electrons and ions in the gas by inelastic collisions with the neutral gas atoms. By this method usually 10 per cent (say) ionisation of the cold gas can be obtained. Stage 2 consists in taking the gas from this few per cent ionisation to 100 per cent ionisation. This can be done by applying a steady electric field to the partially ionised gas so that once again the electrons (because of their very light mass and high mobility) gain energy and cause further ionisation by colliding with neutral gas atoms. As these collisions represent a restriction on the free motion of the electrons in the electric field we say that this ionisation is related to the resistance of the gas. As more and more electrons are produced by this impact mechanism and gain energy from the electric field, so they pass their energy to the ions, this time mainly by elastic collisions since there is a decreasing number of neutral atoms left to ionise. As a consequence both electron and ion temperature rise. This is known as resistive or Joule or ohmic heating. However, as the degree of ionisation grows towards 100 per cent there will be very few inelastic collisions with the result that the electrons tend to pass through the gas relatively unimpeded. This high conductivity (low resistance) of the gas limits the ion temperature attainable to about 10^6 deg. K.; furthermore, as the electrons will make elastic collisions only, and thereby do not lose much energy so they will tend to gain more and more energy from the electric field. This electron " runaway " has proved to be the stumbling block in many of the earlier approaches using pinch discharges since it can cause severe energy loss from the plasma.[5] Stage 3 takes the plasma from 100 per cent ionisation (say, 10^6 deg. K. for deuterium) up to the required thermonuclear temperature of greater than 4×10^8 deg. K. for the D-D reaction.

This is to be achieved by a radial compression of the plasma using magnetic fields acting outside the plasma. Such a magnetic field could be the self field mentioned above and in this case the compression would be the collapse of the current sheet towards the axis due to pinch forces. However, the magnetic field causing the compression may be applied from external coils. Two kinds of compression can be distinguished. Adiabatic or more correctly, isentropic compression occurs when the velocity of collapse is less than the speed of sound in the gas (corresponding to ordinary isentropic compressions in thermodynamics). This kind of compression is extensively used in the " Stellerator " approach where the compression field is produced by external coils ; it was also the compression in the early pinch experiments where the rate of rise of

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current into the gas was not sufficiently great to achieve a supersonic current sheet collapse speed. The second kind of compression is when the velocity of collapse exceeds the speed of sound—hydrodynamic shock wave compression. Here the compression is irreversible (entropy change) so that we consequently obtain a higher temperature from the compression. Besides this higher temperature benefit of shock wave compression there is another good reason for a fast rate of current rise in the gas.

Observations show that pinch discharges suffer from spatial instabilities which distort and break up the plasma.[1] These instabilities take a finite time to grow and it is obvious that the faster the plasma is formed and heated, the less chance there will be that it will be destroyed by instabilities before becoming fully formed and reacting. Simple thermodynamic calculations show that to obtain appreciable changes in the temperature as a result of isentropic compression, a proportionately greater change in density must be effected. However, for a relatively small change in density, the temperature change across a strong shock wave can be made very large indeed. This has led to a proposal for Stage 3, namely starting with a fully ionised gas at a certain temperature T_1, shock heating it to a considerably higher temperature T_2, but a not significantly higher density ρ_2 and then isentropically compressing it to the high final density ρ_3, but not greatly increased final temperature T_3. In many pinch experiments in the past Stages 2 and 3 have tended to be carried out at the same time, i.e. pinch collapse has taken place into a partially (as opposed to fully) ionised gas. For reasons which we shall explain below this is disadvantageous—in fact Stage 3 has never been achieved. It is desirable to have the gas conductivity as high as possible before allowing the pinch to form. Present-day experiments are trying to obtain this separation of Stage 2 from Stage 3. For the purpose of our discussion on shock waves we shall, for simplicity, assume that Stages 1 and 2 have been successfully completed.

Consider Stage 3. An analysis of the collapse of the current sheet surrounding a fully ionised gas was made by Rosenbluth in 1954. This hydrodynamic model of pinch collapse suggested that the imploding current sheet would act like a piston on the gas such that a hydrodynamic shock wave would form and move radially inwards towards the axis ahead of the advancing current sheet—just as a shock wave would form if a piston in a gas-filled tube is given an impulsive motion to a finite velocity. Rosenbluth related the velocity of collapse of the current sheet (and therefore the velocity of the shock wave) to the density of the gas ahead of the shock and the voltage applied to the discharge that caused the current to flow in the first place. More sophisticated analyses of this pinch collapse have been given recently, but the Rosenbluth model highlights the important points quite clearly. If we know the velocity of the shock wave and the conditions in the gas into which it is moving, hydrodynamic shock wave theory enables us to calculate the temperature T_2 behind the shock. The result is

$$T_2 = 5\times10^{10}\,\frac{V}{h}\,\frac{1}{(N_i)}\,0{\cdot}5$$

where

V is the voltage across the discharge (in volts).

h is the length of the cylinder of plasma in the z direction.

N_i is the number of ions per cubic centimetre ahead of the shock wave, i.e. in the undisturbed gas.

It would appear from this equation that the temperature behind the shock wave could be made as large as we wish by merely increasing the factor

$$\frac{V}{h\,(N_i)}\,0{\cdot}5$$

However, with present-day capacitors and heavy current switching circuits there seems to be an upper limit to V of about 100kV—in fact, it has proved difficult to operate as high as this voltage. Furthermore, clearly the length h of the discharge cannot be made too small otherwise a significant portion of the plasma will be in close proximity to the walls and ends of the containing vessel. We can arbitrarily take the minimum value of h to be equal to the diameter $2R$ of the vessel containing the gas. This leaves N_i as the only parameter undetermined.

A more fundamental restriction to the shock heated temperature T_2 obtainable comes in this density term N_i. To understand the implication of this restriction we must consider shock waves in ordinary neutral (non-ionised) gases. Shock waves were first predicted by Riemann about 100 years ago. He found that a finite amplitude compression wave front (finite amplitude meaning a finite as opposed to infinitesimal pressure change across the wave) progressively steepened until it becomes an abrupt discontinuity in the gas across which the velocity, pressure, density, temperature, &c., all change. Nature does not permit such a strict discontinuity and avoids it by the introduction of dissipation, i.e. finite spatial gradients are set up in the gas. In the neutral gas shock wave the most important of these dissipation or transport processes are viscosity (which is due to a velocity gradient and represents a "flow" of linear momentum) and thermal conduction (which is due to a temperature gradient and represents a "flow" of kinetic energy). These transport processes become significant as the wave front tries to steepen and eventually a balance is reached between the steepening effect and the transport effects resulting in the shock wave ceasing to be a strict discontinuity and becoming spread out over a finite spatial distance. This leads to the concept of a characteristic length for the shock transition, i.e. the distance in space over which the shock is spread out. Kinetic theory tells us that the processes of viscosity and thermal conduction in a gas are due to collisions between atoms in the gas. Hence these transport processes are only meaningful if applied over a distance not less than the average distance that a particle travels between collisions—the mean free path. This leads to the well-known result for all but the weakest shock waves that the characteristic length typifying the shock wave thickness is the mean free path in the gas.

For neutral gases the mean free path is readily defined because neutral atoms do not interact over distances much in excess of a few atomic diameters—this being the range of the force field of a neutral atom. Hence atoms in a dilute neutral gas are usually moving in force free space (barring gravity). However, in a fully ionised gas the picture is very different. Here each particle (i.e. electron or positive ion) is charged and therefore surrounded by a Coulomb force field which theoretically extends to infinity. If this was strictly true it would mean that plasma particles were always interacting and that the idea of a mean free path is meaningless. However, as we saw when discussing the limitations of ohmic heating in Stage 2, once the plasma becomes near to 100 per cent ionisation all but a few collisions are elastic ones where there is an exchange of kinetic energy only. Theory shows that such collisions are usually the result of a distant encounter, i.e. the two colliding particles remain considerably separated (their Coulomb force fields, however, interacting) and then move away along slightly changed paths, i.e. plasma collisions tend to be distant-encounter, small-scattering-angle ones. Suppose we fix our attention on any particular plasma particle and follow its path as it moves through the gas; it will suffer a series of collisions with its path changing direction at each collision in some random fashion. We arbitrarily define the mean free path in a fully ionised plasma as the distance that our particular particle must travel, on the average, such that its final path direction is turned through a right angle from its initial path direction. On the basis of this definition, statistical analysis shows that the plasma mean free path is

$$\lambda_{plasma} = 3\times10^4\ .\ \frac{T^2}{N_i}$$

where T is the temperature of the plasma and N_i is the number of ions per cubic centimetre.[6] Values of the ion mean free path for various temperatures and densities obtained from this formula are given in the table below.

The problem of deciding what the thickness of a shock wave in a fully ionised gas is, has not yet been solved convincingly. However, arguing analogously with the neutral gas case we may assume that it also is characterised by the collision mean free path—if anything this is a conservative underestimate

Temperature ahead of shock T_1 deg. K	Velocity of shock wave assuming Mach 10 cm per sec	Shock transit time across tube of $R=10$cm t_{trans} sec	Magnetic field diffusion time in length $L=1$cm t_{diff} sec	Ion mean free path λ_{plasma} cm			Average time between collisions t_{coll} sec			Velocity of sound in fully ionised gas cm per sec	Ion gyro-radius in magnetic field B b_{ion} cm		Ion gyro-frequency in magnetic field B ν sec^{-1}	
				$N_i=10^{14}$	$N_i=10^{15}$	$N_i=10^{16}$	$N_i=10^{14}$	$N_i=10^{15}$	$N_i=10^{16}$		$B=1$ kg	$B=10$ kg	$B=1$ kg	$B=10$ kg
10^5	$5{\cdot}3\times10^7$	2×10^{-7}	6×10^{-6}	3·23	0·32	0·032	7×10^{-7}	7×10^{-8}	7×10^{-9}	$5{\cdot}3\times10^6$	0·4	0·04	$1{\cdot}5\times10^6$	$1{\cdot}5\times10^7$
10^6	$1{\cdot}5\times10^8$	$7{\cdot}5\times10^{-6}$	2×10^{-4}	323	32·3	3·23	2×10^{-5}	2×10^{-6}	2×10^{-7}	$1{\cdot}5\times10^7$	1·4	0·14		

of its thickness, especially in the case of strong shock waves. If this is so, then we must ensure that the dimensions of the vessel containing the plasma to be shock heated are considerably in excess of this shock wave thickness—otherwise no shock will exist (or more strictly, no shock wave will form) and none of the benefits of shock heating will be obtained. Suppose we postulate a vessel radius of 10cm (which is about the size used in most pinch experiments excepting the big machines) then our plasma mean free path must be considerably less—say, 1cm.

So far we have said nothing about the magnitude of the particle density to be expected in a fusion reactor. Calculations of the optimum gas parameters show that for the *D–D* reaction the temperature must be not less than 4×10^8 deg. K. and that the operating particle density should be about 10^{15} to 10^{16} particles per cubic centimetre; this will give a reaction power density of 100W per cubic centimetre of reacting gas which is the sort of power density achieved in a fission reactor. If the temperature is lower than the figure above then the plasma will not "ignite," whilst if the density is lower than that quoted then the reaction power density in the gas will be too small for thermodynamic manipulation. Alternatively, if the gas density exceeds 10^{16} particles per cubic centimetre then the power density in the gas becomes prohibitive and the magnetic containment problems become formidable. Hence, in Stage 3 we must end up with a density of about 10^{16} per cubic centimetre. As the maximum density change across a strong shock wave in a fully ionised gas is 4 we see that the initial gas density for Stage 3 should be not less than $N_i=5\times10^{14}$, say. This will allow for any reflected shocks (see below) and also for any subsequent isentropic compression. A glance at the table shows that no hydrodynamic shock will be formed unless N_i exceeds about 3×10^{14} at $T=10^5$ deg. K. and 3×10^{16} at $T=10^6$ deg. K., i.e. there is a value of N_i at any temperature, below which the shock wave method is invalid.

These mean free path considerations, together with the highest voltages conveniently usable, therefore limit the term $V/(N_i)^{0.5}$ in the expression for the temperature T_2 behind the shock wave. The more sophisticated calculations of pinch collapse already referred to show that this limiting temperature behind the initial shock wave based on the type of argument given above is about 2×10^6 deg. K. Even if allowance is made for the fact that the imploding shock wave will be reflected from near the axis and that therefore it will further shock heat the gas it has already passed through on its way towards the axis, then the maximum temperature attainable[7] in the twice shocked gas is still only about 4×10^6 deg. K. Clearly a considerable degree of isentropic compression will be required to raise the gas to the final thermonuclear ignition temperature. Such a large isentropic compression is undesirable since it would raise the particle density to an embarrassingly high level.

There is a slightly different way of looking at this limitation to shock wave heating that will be useful in our discussion of the hydromagnetic shock. Instead of using the mean free path directly let us consider the collision interval t_{coll}, i.e. the average time that elapses between two consecutive collisions of any particle; clearly this is merely the mean free path divided by the particle velocity. The table shows values of the collision interval for various sensible values of temperature and density. Now our shock wave will take a certain time t_{trans} to cross the container—the exact value will depend on the speed of the shock. Let us take the Mach number of the shock to be $M=10$; this is a strong shock wave. Let us also take a vessel radius of 10cm then the table shows values of t_{trans}. If we compare the collision interval with the shock transit time using the table then we see that there will be no time for collisions at all if the initial density is not greater than the values mentioned in an earlier paragraph. Clearly, no hydrodynamic shock wave (which relies on collisions in the gas in order to form at all) will result. It would therefore appear that unless we can find means of operating at considerably higher voltages than 100kV and in considerably larger containers, hydrodynamic shock heating will be limited in its utility.

However, there is another side to the story. It was remarked above that pinched discharges suffer from instabilities of several types. To achieve partial stability it has been found desirable to have a magnetic field inside and along the axis of the discharge, i.e. a B_z field. This field can be said to give a backbone to the plasma because if the plasma deforms then the B_z magnetic field acts like a piece of elastic and tries to restore the plasma column to its original shape. Such a field would be produced by windings external to the discharge vessel. It should be stressed that this B_z field is "trapped," i.e. locked inside the plasma column as we shall see in the next paragraph. It should not be confused with the magnetic field that drives the current sheet inwards and thereby forms the hydrodynamic shock wave.

Let us return to our model of a 100 per cent ionised gas in the form of a plasma cylinder. If we turn on our B_z stabilising field after Stage 2 is complete, then we have the problem of trying to get a magnetic field into a good electrical conductor. Magnetic fields diffuse into conductors with a characteristic time $t_{diff}=4\pi.\mu.\sigma L^2$ where μ is the plasma permeability (value unity) and σ is the plasma conductivity. L is some characteristic length over which the field diffusion is taking place: we shall take it equal to $0{\cdot}1R$ where R is the radius of the vessel. Advanced kinetic theory enables us to calculate the conductivity of a fully ionised gas and it is found to be a function of temperature only[6]. The table gives values of t_{diff} for various temperatures; we see that the magnetic field diffusion time is long compared with the shock transit time. Hence in order to have the benefit of the B_z stabilising field in the discharge it must be established before the plasma is created in and around it. Once the plasma is formed then this B_z field will be trapped inside since its diffusion time outwards is equal to its diffusion time inwards. If now we apply our external voltage which causes current to flow then pinch effect will occur and a shock may form as predicted by the Rosenbluth hydrodynamic analysis. However, this shock wave will be moving into a plasma containing the trapped B_z stabilising field (the direction of this field—along the axis—being normal to the direction of shock propagation). There will be an electromagnetic interaction between the radially imploding conducting flow and the trapped B_z field; the energy involved in this interaction must be allowed for when writing down the equations controlling the shock wave. In this case the shock wave is not a hydrodynamic one but rather a hydromagnetic one because of this additional interaction[8]. As the diffusion time is considerably in excess of the shock wave transit time from the table, the magnetic field will be "collected up" by the advancing shock wave as well as the gas and both gas and trapped field will be compressed in this motion towards the axis. Work must be done to compress the field as well as the gas. This requirement of doing work on a magnetic field will result in a lower temperature behind the hydromagnetic shock wave than in the hydrodynamic case, because less energy is available to manifest itself as thermal (temperature) energy. It would thus appear that hydromagnetic shocks are not as effective in gas heating as their hydrodynamic counterparts. This limitation is none too serious because conditions can be arranged to "maximise" the shock heating by a judicious choice of magnetic fields in front of and behind the shock. Any limitation of this sort is, however, outweighed by a rather unique advantage which is of the greatest importance, namely the characteristic length for hydromagnetic shock thickness.

It is well known that charged particles spiral around magnetic lines of force whilst moving along them. Connected with this gyro-motion are two parameters: the gyro frequency $\nu=eB/2\pi m$ which is the number of revolutions per unit time made by the particle and the gyro-radius $b=mv/eB$ (where v is the component of the particle velocity normal to B) which is the radius of the circle described by the charged particle. If the plasma conditions are such that the collision frequency (the reciprocal of the collision interval t_{coll}, i.e. the number of collisions per unit time) greatly exceeds the gyro-frequency such as would occur in a high density, relatively low temperature plasma, then any particle will not make much of a spiralling motion before being hit by another particle. This environment tends to make the plasma behaviour isotropic. In this case a hydromagnetic shock wave behaves very much like a hydrodynamic shock wave in that the dissipation processes are viscosity and thermal conduction and the shock transition is characterised by the mean free path. In this case the hydromagnetic shock is said to be "collision-dominated." It can be shown that for these plasma conditions the gyro-radii of the charged particles greatly exceeds the mean free path. However, if the plasma conditions are such that the collision frequency is very much less than the gyro-frequency, such as would be found in a low density, high temperature plasma (such as a fusion plasma) then a charged particle will make many gyrations before suffering a collision. This tends to make the plasma behave differently in different directions, i.e. it is anisotropic. If now we consider the transport processes of viscosity and thermal conduction in a plasma, then the presence of a magnetic field will tend to tie the particles to the field lines (for the case when the collision frequency is very much less than the gyro-frequency) so that the transport coefficients normal to the field will be considerably reduced. It is this reduction in the magnitude of the transport coefficients in a direction normal to the magnetic field that is important in the hydromagnetic shock. We have already seen that viscosity and thermal conduction balance the steepening effect in the neutral gas hydrodynamic shock. However, for the hydromagnetic shock in a low density, high temperature plasma they can be so small as to be ineffective. What then limits the steepening? At the present time there is no definite answer to this question although there are several current theories. If viscosity and thermal conduction are ruled out and collisions in the gas are unimportant in deciding

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the gas behaviour then the collision mean free path is apparently not the important characteristic length for the shock transition. Hence, in this case of a "collision free" hydromagnetic shock we must look for another characteristic length in the plasma which is less than the mean free path—the gyro-radius of the particles is a possibility. However, which gyro-radius—that of the ions, or that (much smaller) of the electrons?

Furthermore, a more subtle problem arises. For the hydrodynamic shock and the collision-dominated hydromagnetic shock, the irreversible entropy change (which gives us the temperature benefits of shock compression compared with isentropic compression) is produced by collisions. The whole of the classical kinetic theory of gases is based on the concept of particle collisions, whilst the law of entropy increase (Boltzmann's *H*-theorem) which is fundamental in thermodynamics likewise relies on collisions to produce the irreversibility. However, we are now considering a shock wave in the limit of no collisions! As soon as we write down the equations that govern the gas and magnetic field behaviour across the shock we automatically have stated as a consequence that there will be an increase in entropy in the shock transition. If collisions between particles are of minor or no importance what process or processes produce the required entropy increase?

As remarked above, several theories (or more accurately, hypotheses) exist. One theory suggests that hydromagnetic waves are produced at the shock and these waves interact with each other and suffer scattering—this scattering (or randomising) produces an increase of entropy. Associated with this mechanism is the gyro-radius of the ions as the characteristic length of the shock transition.[9] Another theory suggests that the characteristic length is the geometric mean of the ion and electron gyro-radii.[10] Other theories suggest even smaller characteristic lengths in the plasma and other mechanisms to produced dissipation.

Regardless of what physical mechanism is involved, the important feature of these speculations is that hydromagnetic shock heating of a gas can occur under conditions where the mean free path is larger than the container—provided that the characteristic length of the hydromagnetic shock transition (whatever it may be) is less than the dimensions of the vessel. This fact has led to extensive theoretical studies of collision-free hydromagnetic shock waves to see how useful they might be in producing thermonuclear temperatures. Not much is known experimentally—some published results are available from the Avco Laboratories[9] and also from the Livermore Laboratories.[11] Such experiments are very difficult to perform. Most of the pinch studies have utilised shock waves propagating into partially (as opposed to fully) ionised gases as remarked earlier. The presence of un-ionised atoms complicates the collision process and furthermore the low electrical conductivity of the gas reduces t_{diff} to values such that significant magnetic field diffusion occurs in the time scale of the pinch, thereby producing a mixture of hydrodynamic and hydromagnetic shock waves. Present laboratory studies tend to try and produce collision free hydromagnetic shocks in special apparatuses not necessarily capable of providing thermonuclear reactions.

Groups in England and Germany are known to be working along these lines and new theories and new experimental results were reported at the recent Salzburg Conference on thermonuclear problems. However, the outstanding questions related to collision-free hydromagnetic shocks remain to be answered.

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Chart Method for Pipe Stress Calculations

By H. PORTER*

Most companies engaged on large-scale design and fabrication of high-temperature pipework systems make flexibility analyses the responsibility of separate stress departments. Such an arrangement is economic and indeed essential when complicated multi-anchor pipework arrangements are to be critically examined. The amount of arithmetic necessary for a precise solution for stresses in even simple pipe-runs makes the use of calculating machines almost essential and even when using standard sheets for the calculations, the complexity of the operations makes it preferable to use "specialist" staff. For preliminary design work, and where a less precise solution will suffice, there are approximate methods available such as the Guided Cantilever and Mitchell-Bridge methods. These methods are, however, based on simplifying assumptions which may lead to an indicated maximum stress in a pipeline which is incorrect in value and in position. Chart methods are also available, but these are only applicable to quite simple pipe configurations. The method described below has been developed to enable a reasonably precise solution for stress to be obtained at drawing-board level in two-anchor pipe systems. By the use of a specially prepared chart upon which a tracing of the pipe outline is placed, the arithmetic required is largely reduced to the simple addition of indicated numbers, and the method has been used successfully by staff with no previous "stress" experience. The results obtained compare closely with those obtained by the generally accepted analytical methods.

Principles of the Method

THE method is an adaptation of the Elastic Centre and a graphical method described by Cocks.† Consider a pipe anchored at one end as shown in Fig. 1 (*a*) and subjected to a rise in temperature. The free end will move by the amounts Δx and Δy. If the pipe were anchored at each end, it would take up the shape shown in Fig. 1 (*b*) with the resulting forces H and V and the moment M acting at the right-hand end.

Consider now the same pipe at temperature, anchored at the left-hand end only, but with a rigid bar attached to the free end and extending to some point C. It will be apparent that if a particular point is chosen for C, forces H and V only applied there, will produce the same deformation and end moment as in Fig. 1 (*b*). The Elastic Centre Method assumes that the position for C is at the "centre of flexibility" of the pipe system and that this lies at the centre of gravity of a line representing the pipe if each element of the line has a mass proportional to its flexibility. The centre of flexibility will therefore be displaced from the centre of gravity of a pipe system towards any bends or more flexible sections.

When the position of point C has been established, the forces H and V necessary to produce given deflections Δx and Δy may be determined as follows.

Consider the deflection of the free end of a

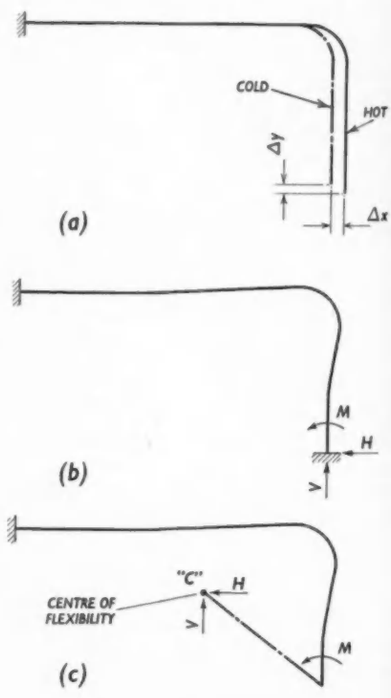

Fig. 1(*a*)—Pipe freely expanding

Fig. 1(*b*)—Hot pipe fully restrained each end

Fig. 1 (*c*)—Hot pipe with forces acting at centre of flexibility

* Nuclear Projects Department, John Thompson Water Tube Boilers, Ltd., Wolverhampton.
† Proc. Inst. Civil Engineers, 1932.

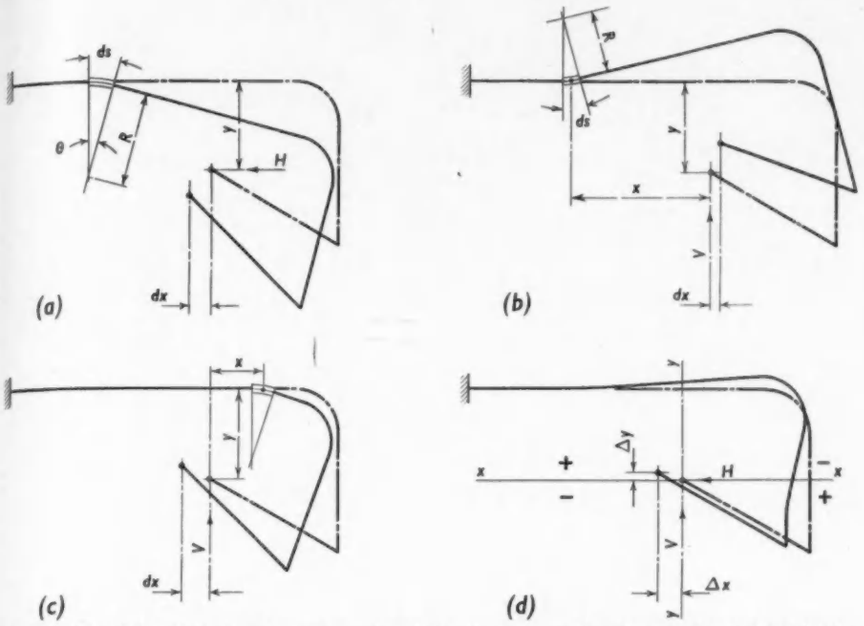

Fig. 2 (*a*), (*b*) and (*c*)—Deflections due to forces *H* and *V* acting on particular elements (*d*)—Total deflections due to forces *H* and *V* and signs of *xyds*. for each quadrant

pipe by the action of force *H* on an element of the pipe as shown in Fig. 2 (*a*). From simple bending theory :

Bending Moment $= M = Hy$

$$\sin\theta = \frac{ds}{R} = \frac{Mds}{EI} = \frac{Hyds}{EI}$$

$$dx_{(H)} = y\sin\theta$$

$$= \frac{Hy^2ds}{EI}$$

Similarly the force *V* acting on the same element as shown in Fig. 2 (*b*) produces a deflection in the opposite direction

$$dx_{(V)} = -\frac{Vxyds}{EI}$$

For an element located as shown in Fig. 2 (*c*) it will be seen that force *V* will produce a deflection in the same direction as force *H*.

The total deflection in the *x*-direction due to forces *H* and *V* applied at the centre of flexibility may therefore be taken as

$$EI\Delta x = \Sigma Hy^3ds - \Sigma Vxyds$$

where the individual values of *Vxyds* are taken as positive or negative depending upon which quadrant the element occurs between *x* and *y* axes drawn through the centroid, and also on the direction of the applied forces.

The total deflection in the *y*-direction may similarly be taken as

$$EI\Delta y = \Sigma Vx^2ds - \Sigma Hxyds$$

with the same considerations to the signs of individual values of *Hxyds*.

For forces *H* and *V* acting in the directions shown in Fig. 2 (*d*) the signs of *Jxyds* for elements in each of the quadrants will be as indicated.

The Calculation Chart

To determine the position of the centre of flexibility of a pipe system and the values of Σx^2ds, $\Sigma xyds$, &c., by the usual methods, a large amount of arithmetic is required. By the normal graphical methods a considerable amount of scaling and multiplication of scaled dimensions is necessary. A chart may be prepared, however, which if laid beneath a tracing of the pipe outline, will indicate values of x^2, y^2 and xy for any point on the pipe about a given centre. A quarter section of such a chart is shown in Fig. 3. For use with the equations as given below, the divisions of the chart should measure $\frac{1}{8}$in, and the resulting overall size is convenient for drawing-board use.

When used as described below with a tracing of the pipe outline divided into suitable small elements of length—Fig. 4—the position of the centre of flexibility and the resulting values of $\Sigma xyds$, &c., may be easily obtained by the simple addition of chart numbers read through the tracing. Substitution of these results together with the known amounts of expansion or deflection into simultaneous equations will give values of the end forces *H* and *V*. The complete calculations for stresses in two-anchor pipe systems may be made on one drawing sheet and may be easily checked at all stages.

Use of the Chart

The centre of flexibility of a pipe system with two anchors may be found by dividing a line-drawing of the pipe into small elements of length and taking moments of each element about fixed axes as would be done for finding

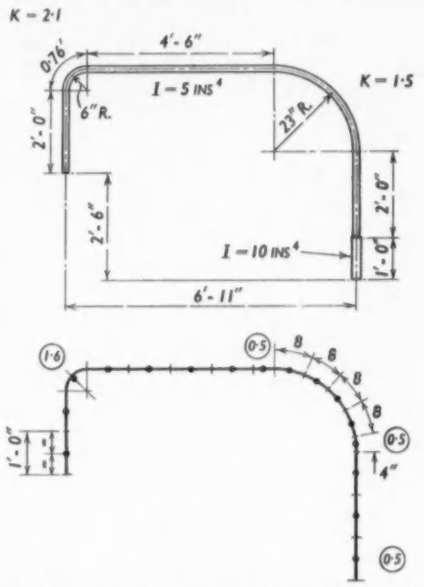

Fig. 4—Typical pipeline and line-drawing divided into elements of length

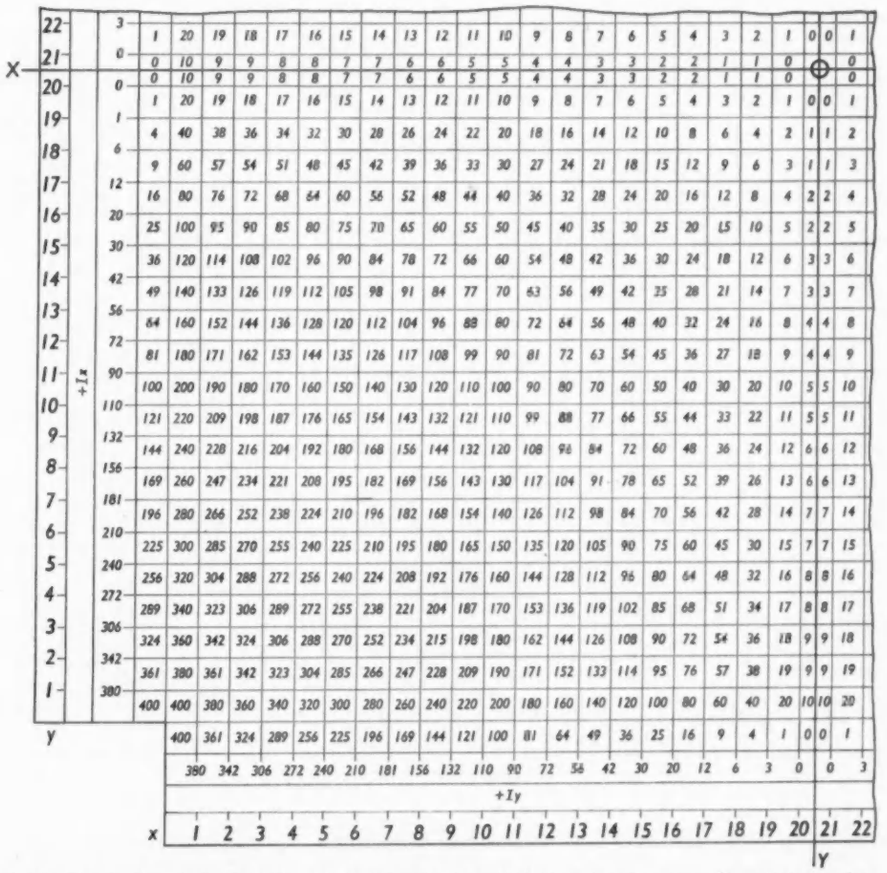

Fig. 3—Construction of the calculation chart. The actual chart divisions should measure $\frac{1}{8}$in and the numbers are repeated in each quadrant

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the centre of gravity of such a pipeline. It is necessary, however, to allow for the differing flexibilities of various sections of the pipeline. This may be done by assuming that each element has a mass proportional to the flexibility of the pipe at that point. Alternatively, the lengths of the elements may be made proportional to the respective stiffnesses and each assumed to have equal mass.

In bent sections of a pipeline, where the flexibility is greater due to the flattening of the cross section when bending, an element may be considered to have a mass equal to K times that of a straight element of similar length where

$$K=\frac{1\cdot65r^2}{tR}$$

r=Mean radius of pipe.

t=Thickness of pipe.

R=Bend radius.

Where a pipeline is composed of differing diameters of straight pipe, the elements may be considered to have a mass inversely proportional to the respective moments of inertia of the various sections. When a valve or some other relatively inflexible fitting occurs in a pipeline, the elements in these sections may be assumed to have zero mass.

Fig. 4 shows a typical pipeline and a line-drawing suitably divided into elements for use with the calculation chart. The line-drawing is divided into equal "mass" units as far as possible and the centroid of each element marked with a point. Where an element is more or less than the standard "mass" the ratio is marked alongside the particular centroid.

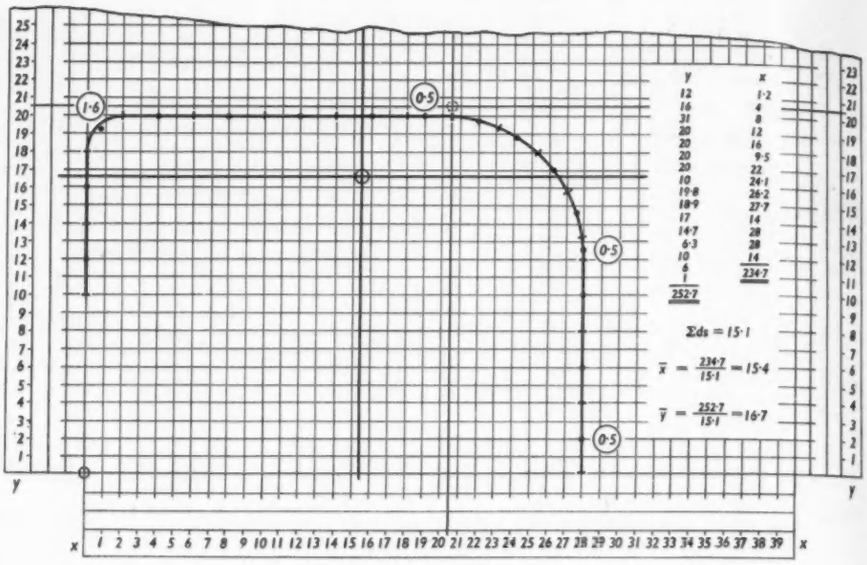

Fig. 5—Using the calculation chart to find the centre of flexibility

The tracing of the pipe-run is now laid over the lower left-hand corner of the chart as shown in Fig. 5. The moment arms to each element centroid in the x and y directions may be read from the linear scales at the edges of the chart. Where an element is of more or less than the "standard" mass the reading should be multiplied by the ratio marked alongside. The sum of these readings divided by the total length of the line in standard mass units will give the distances $\bar{x}$ and $\bar{y}$ to the centre of flexibility in chart units. As shown in Fig. 5 the complete arithmetic may be carried out on the pipe drawing sheet.

Calculating the Flexibility Coefficients

The drawing of the pipe used for determining the centre of flexibility may be used in conjunction with the calculation chart for

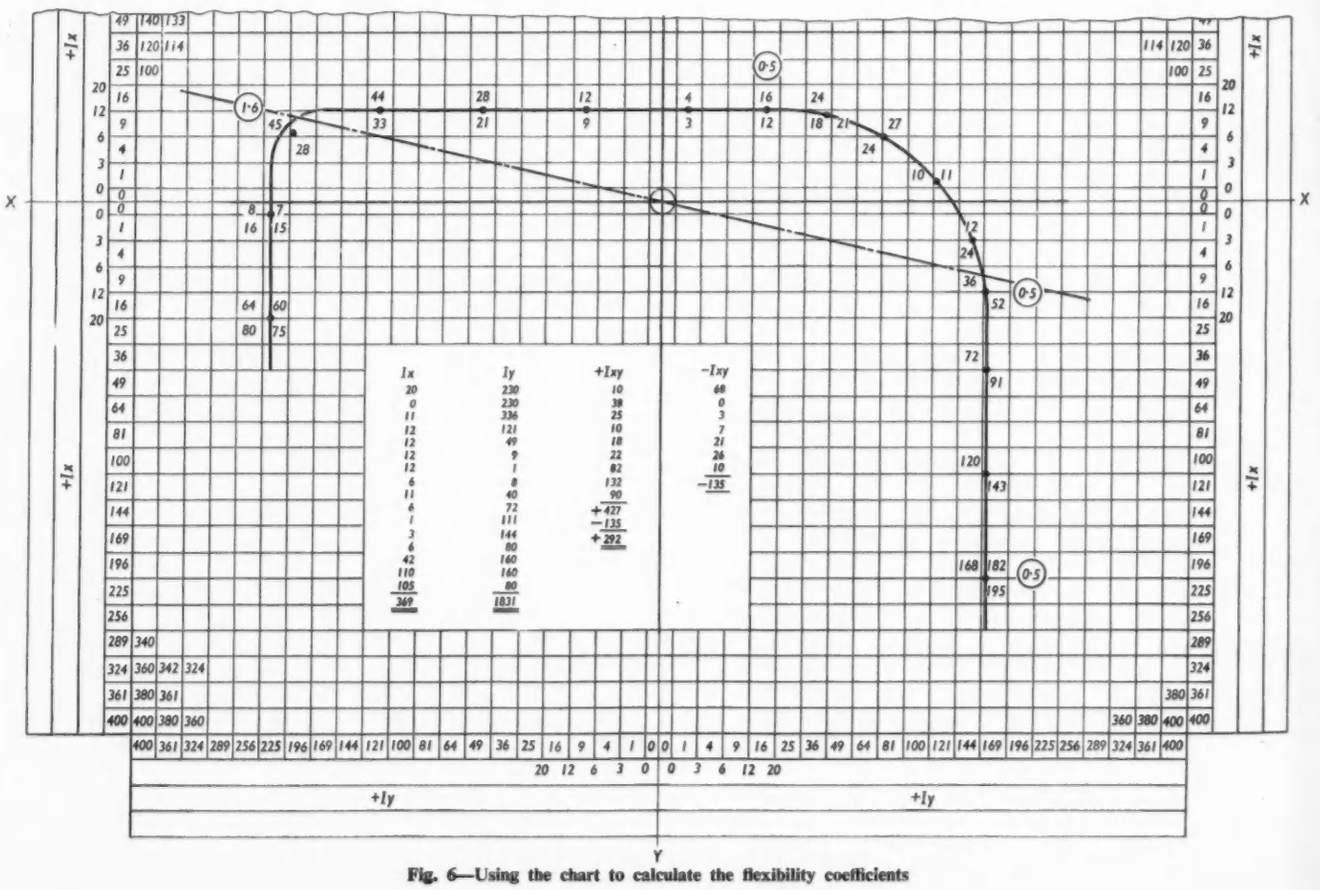

Fig. 6—Using the chart to calculate the flexibility coefficients

finding values of $\Sigma x^2 ds$, $\Sigma xyds$, &c., which appear as coefficients in the final simultaneous equations given below. The drawing is repositioned such that perpendicular axes drawn through the centre of flexibility intersect at the point O at the centre of the chart as shown in Fig. 6. Commencing at one end of the pipe, the values of $x^2 ds$ and $y^2 ds$ for each element may be read from the scales marked *Iy* and *Ix* at the edges of the chart. The readings for elements marked as being more or less than the standard mass unit should again be multiplied by the ratio indicated. All readings of *Ix* and *Iy* may be taken as positive irrespective of in which quadrant of the chart they occur, and simple addition of the readings gives the value of coefficients to be used in the final equations.

The value of *xyds* for each element is given by the numbers which appear in the squares of the chart. The numbers given refer to an element centroid which appears exactly at the centre of a square, but by simple interpolation between numbers in adjoining squares the value for any position may be quite accurately determined by inspection. It is, however, necessary to take into consideration the position of the element with respect to the centre of flexibility to determine the signs of the individual values of *xyds*. If the deflections Δx and Δy of the pipe are assumed positive in the direction to the left of the chart and in the vertical directions, all elements appearing in the upper left and lower right quadrants of the chart are assigned positive values, and all other readings are taken as being negative. Addition of the readings for all elements will give the value of *Ixy* to be used in the final equations.

The complete calculation of *Ix*, *Iy* and *Ixy* may be conveniently carried out on the drawing sheet as shown in Fig. 6. It is only necessary to be particularly precise in taking readings of the higher numbers, and the whole operation takes very little time.

Calculating the End Forces and Moments

For single-plane pipes, the values of *Ix*, *Iy* and *Ixy* as obtained from the calculation chart may be used with the given deflections or expansions Δx and Δy in the following equations to obtain values of forces *H* and *V* acting at the anchor points.

$$H=\frac{S^2EI}{243L}\ \frac{(Iy\Delta x+Ixy\Delta y)}{IxIy-(Ixy)^2}$$

$$V=\frac{S^2EI}{243L}\ \frac{(Ix\Delta y+Ixy\Delta x)}{IxIy-(Ixy)^2}$$

where

H and *V* = End forces (lb) in *x* and *y* directions.

S = Scale of pipe tracing (inches to the foot).

Δx and Δy = Deflections or expansions (inches).

E = Modulus of Elasticity (lb per square inch).

I = Moment of inertia of basic pipe (in^4).

L = Actual length of standard element in basic pipe (feet).

As an example, assume the pipe shown in Fig. 4 anchored at each end and raised to a temperature of 300 deg. Fah. from 70 deg. Fah. Taking the coefficient of expansion as 6×10^{-6}, the free expansions would be

$$\Delta x=l_1 k\Delta t=83\times6\times10^{-6}\times230=0{\cdot}114\text{in.}$$

$$\Delta y=l_2 k\Delta t=30\times6\times10^{-6}\times230=0{\cdot}041\text{in.}$$

The chart readings shown in Fig. 6 were obtained by using a drawing to a scale of $1\frac{1}{2}$in equals 1ft and the forces *H* and *V* are given by

$$H=\frac{(1{\cdot}5)^3\times30\times10^6\times5}{243\times1}\ \frac{(1831\times0{\cdot}114)+(292\times0{\cdot}041)}{(369\times1831)-(292)^3}$$

$$=496\text{ lb.}$$

$$V=\frac{(1{\cdot}5)^3\times30\times10^6\times5}{243\times1}\ \frac{(369\times0{\cdot}041)+(292\times0{\cdot}114)}{(369\times1831)-(292)^3}$$

$$=109\text{ lb.}$$

The value of the bending moment at any point in the pipe may then be found by assuming that the above forces *H* and *V* are acting at the centre of flexibility. It is usually convenient to draw in the "thrust line" to determine where the maximum bending moment will occur. This line will pass through the centre of flexibility and will be in the direction of the resultant of the forces *H* and *V*, and the bending moment at any point in the pipe will be proportional to the distance of the point perpendicularly from the thrust line. The thrust line for the expansions given in the example above is drawn in on Fig. 6, indicating maximum bending moment at the right-hand end of the pipe.

Application to Three-Plane Pipes

The chart may be used with three-plane pipelines having two anchors by drawing three projected elevations of the pipe (in *XX*, *XY* and *YZ* planes) and taking readings successively on each view. The pipe-drawing is divided into elements as for a single-plane pipe and the positions of each element centroid projected on to each view. It is necessary, however, to take into account the greater flexibility of pipes in torsion. Since a section of pipe in a three-plane system will be in bending in two planes and in torsion on the third, a common centre of flexibility for all planes cannot strictly be true. No great error in the final result is introduced, however, if the centre of flexibility is determined by using the method exactly as described for single-plane pipes. It is necessary to do this of course only on two elevations, the position being then projected on to the third view.

The values of the flexibility coefficients may also be determined as for single-plane pipes by taking chart readings for each view. The greater flexibility of pipes in torsion is allowed for by multiplying the chart readings for any element which lies in a direction normal to the paper in the plane being considered by the factor 1·3. Addition of the chart readings will give values of (*Ix*, *Iy*, *Ixy*), (*Ix*, *Iz*, *Ixz*) and (*Iy*, *Iz*, *Iyz*) for the *XY*, *XZ* and *YZ* planes respectively. The sum totals of the values of *Ix*, *Iy*, *Iz*, *Ixy*, *Ixz* and *Iyz* may then be used in the following simultaneous equations to give values of forces *X*, *Y* and *Z* for given deflections Δx, Δy and Δz.

$$XIx-YIxy-ZIxz=\frac{S^2EI}{243L}\Delta x$$

$$-XIxy+YIy-ZIyz=\frac{S^2EI}{243L}\Delta y$$

$$-XIxz-YIyz+ZIz=\frac{S^2EI}{243L}\Delta z$$

The bending and torsional moments at any point in the pipeline may be determined by assuming that the forces *X*, *Y* and *Z* are acting at the centre of flexibility.

Application of the Results

In a single-plane pipe the bending stress at any point is given by

$$S_b=i\frac{M}{Z}$$

In three-plane pipes the combined bending and torsional stress is given by

$$S=\sqrt{S_b^2+4S_t^2}$$

where

$$S_b=i\frac{M_b}{Z}$$

$$S_t=\frac{M_t}{2Z}$$

M_b = Bending moment.

M_t = Torsional moment.

Z = Pipe section modulus.

i = Stress intensification factor.

To relate the indicated results with allowable stresses, &c., reference should be made to the British Standard B.S.806 : 1954 or the American "Code for Pressure Piping" A.S.A. B31.1-1955. Values of the stress intensification factors (*i*), which are applied where the point being considered is at a bend or a discontinuity such as a branch, are also given in the American Code.

Accuracy of the Chart Method

In the commonly used analytical methods the amount of arithmetic required always introduces the possibility of a large incidence of error and the allocation of the correct sign to the many individual pieces of arithmetic demands a clear understanding of the principles involved. By use of the chart as described above, the solution for two-anchor pipe systems is reduced largely to a systematic reading and addition of indicated numbers which may be carried out by staff with no particular knowledge of the mechanics involved. Although a slight compromise is made in taking into account the effects of torsion in three-plane solutions, the overall accuracy of the method is largely governed by the accuracy of the pipe drawing and by the number of elements into which it is divided.

For quite precise solutions the pipe drawing should be made to the largest scale that the chart will accommodate and the elements made generally not more than three or four chart divisions long. In many cases approximate solutions using larger elements may be quickly obtained to determine whether a more precise treatment is warranted. A drawing-board chart calculation for an example of a square corner three-plane pipe given Kelloggs *Design of Piping Systems* gave a maximum stress of 8400 lb per square inch. The precise result by the General Analytical Method is given as 8700 lb per square inch and the results by two approximate methods are quoted as 13,220 lb and 6580 lb per square inch.

Some comparisons have been made between the results for practical two-anchor pipelines obtained by the use of the chart and slide rule and those obtained by the Grapho-Analytical Method. In all cases the final stress values have agreed within a few per cent and the time required by the chart method has been approximately one-quarter of that needed for the analytical method.

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Technical Contributors Section (*Continued*)

Metallic Thick-Walled Spherical Pressure Vessels at Elevated Temperatures

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The purpose of the investigation was to make a theoretical analysis of the distribution of stress and strain rate in metallic thick-walled spherical pressure vessels, subject to high internal and external pressures at elevated temperatures. A theoretical analysis, based on creep stress-strain-time relations, derived in an extensive investigation of the creep of metals, under complex stresses at elevated temperatures, has been prepared for the general case, where creep strains and elastic strains occurring in a spherical vessel, as a result of internal and external pressure at elevated temperatures, are both of significant order. As a result of the above analysis, it is possible to predict the changes of stress and strain rate occurring with time, in a spherical pressure vessel, under the conditions stated.

AN analysis of the stresses and strains in a thick-walled sphere, under internal and external pressures giving rise to purely elastic strain, was made initially by Lamé,* and subsequently various authors have dealt with the same problem. No attention has, however, been given to the corresponding problem which occurs in actual high-temperature plant practice of a thick-walled sphere subject to internal and external pressures under such circumstances that over a considerable portion of the intended life of the structure, creep strains and elastic strains are both of significant order. It is obviously of practical importance that an analysis be made of the changes of distribution of stress and strain rate with time in such cases and this article is directed towards this end.

As a corollary, in an Appendix to this article, the special case is considered where elastic strain becomes unimportant relative to creep strain. Such a case may arise after very long periods of operation at moderately high working temperature, or after relatively short periods at very high temperatures. This represents an extreme of the general case and is utilised in this capacity in the development of the general theory.

NOTATION

Symbol	Definition
r	Radius.
u	Radial displacement.
α	du/dr, radial strain.
β	u/r, circumferential strain.
P	Radial stress.
Q	Circumferential stress.
a	Internal radius.
b	External radius.
p	Internal pressure.
q	External pressure.
E	Young's modulus.
ν	Poisson's ratio.
J_2	$1/6\{\Sigma(P-Q)^2\}$, the second invariant of stress.
$\phi(t)$	Function of time.
α'	Radial strain rate.
β'	Circumferential strain rate.
$F(J_2)$	Function of J_2.
A, n	Constants.
G	$\frac{A\phi(t)}{3^{(n+2)/2}}$
H	$\frac{(1-\nu)}{E}$
B	$\frac{a^3b^3(p-q)}{(b^3-a^3)}$
x_0	$-\frac{3}{2}\frac{B}{r^3}$
K	$\frac{(-1)^{\frac{n+1}{n+1}}3^{\frac{n+1}{n+1}}a^3b^3(p-q)^{\frac{n+1}{n+1}}}{\left[2(n+1)\{b^{3/n+1}-a^{3/n+1}\}\right]^{\frac{n+1}{n+1}}}$
x_∞	$-\left[\frac{K}{r^3}\right]^{(1/n+1)}$
C	$\frac{x_\infty^{n+1}}{x_0}\cdot\frac{\left(\frac{3}{2}\right)^n(p-q)^n(b^3-a^3)}{\left[n+1\{b^{3/n+1}-a^{3/n+1}\}\right]^{n+1}}$
$\theta't$	$\frac{EA\phi(t)}{3^{(n+2)/2}(1-\nu)}$
θ_t	$\int_0^t\theta'_t dt$

* Lamé, G. "Leçons sur la theorie mathematique de l'elasticité des corps solides," Bachelier, 1852.

THEORETICAL RELATIONS BETWEEN STRESS, STRAIN RATE AND TIME, FOR THICK-WALLED SPHERICAL PRESSURE VESSEL

From symmetry it may be concluded that the only displacement in this problem is radial, being such that concentric spherical surfaces remain spherical and concentric after strain. Denote the unstrained distance of a particle from the centre of the sphere by r, and the strained distance by $(r+u)$. The radial strain is then clearly $\alpha=du/dr$, and the circumference of any great circle on the surface of the sphere of radius $(r+u)$ has been changed by strain from $2\pi r$ to $2\pi(r+u)$. The circumferential strain is accordingly

$$\beta=\frac{2\pi u}{2\pi r}=\frac{u}{r}.$$

This is the strain in every direction perpendicular to the radius r. Thus the three normal strains in the directions of three perpendicular axes, one of which is in the radial direction and the other two in a plane touching the sphere of radius $(r+u)$, are respectively,

$$\frac{du}{dr}, \frac{u}{r}, \text{ and } \frac{u}{r}.$$

Relative to these axes the shear strains are zero.

Corresponding to the above strains, the problem is characterised by a radial stress P, and a circumferential stress Q, which latter is the same in every direction perpendicular to the radial direction; no shear stresses are present relative to these axes of reference. Inasmuch as elastic stresses and strains are instantaneously also the total stresses and strains at zero times,† the same nomenclature will be used when stresses and strains corresponding to mixed elastic and creep conditions are characterised. Considering a thick-walled sphere of internal radius a and pressure p, and external radius b and pressure q, the following expressions (derived by Lamé) represent the elastic or zero time values of P, Q, α and β where E is Young's modulus and ν is Poisson's ratio for the material and temperature concerned.

† It is assumed that the working temperature is such that initial time-independent plastic strain is absent.

Stresses at Zero Time.—

$$P=\frac{1}{(b^3-a^3)}\left\{(a^3p-b^3q)-\frac{a^3b^3}{r^3}(p-q)\right\}$$

$$Q=\frac{1}{(b^3-a^3)}\left\{(a^3p-b^3q)+\frac{a^3b^3}{2r^3}(p-q)\right\}$$

Strains at Zero Time.—

$$\alpha=\frac{du}{dr}=\frac{1}{E}\{P-2\nu Q\}$$

$$=\frac{1}{E}\left(\frac{1}{b^3-a^3}\right)\left\{(a^3p-b^3q)(1-2\nu)-(p-q)\frac{a^3b^3}{r^3}(1+\nu)\right\}.$$

$$\beta=\frac{u}{r}=\frac{1}{E}\{Q-\nu(P+Q)\}$$

$$=\frac{1}{E}\frac{1}{(b^3-a^3)}\left\{(a^3p-b^3q)(1-2\nu)+(p-q)\frac{a^3b^3}{2r^3}(1+\nu)\right\}.$$

The above relations concern the elastic case. In order to approach the general case of concurrent elastic and creep strain, it is necessary to make a further assumption concerning purely creep strain in any current time t. The assumption made is that the rate of creep at any point in the vessel is a function only of the current stress system, and the current time, and is independent of the path by which the current stress system has been reached. This is in effect equivalent to an assumption of the mechanical age-hardening theory of creep. In the present application, the assumption offers certain advantages of mathematical simplicity over other possible assumptions. Making this assumption we may write down‡ the equation representing the total (elastic and creep) strain rate corresponding to the change with time of stresses P and Q, at specific points in the vessel.

These equations are stated immediately below, $F(J_2)$ denoting a function of the second stress invariant, defined on the assumption of material isotropy as :

$$J_2=\frac{1}{6}\{\Sigma(P-Q)^2\}, \text{ and } \phi(t),$$

a function of the current time.

$$\alpha'=\frac{\partial}{\partial t}\left[\frac{du}{dr}\right]=\frac{2}{3}F(J_2)\left[P-\frac{1}{2}(2Q)\right]\phi(t)+\frac{1}{E}\frac{\partial(P-2\nu Q)}{\partial t}$$

$$=\frac{2}{3}F(J_2)[P-Q]\phi(t)+\frac{1}{E}\frac{\partial[P-2\nu Q]}{\partial t}$$

$$\beta'=\frac{\partial}{\partial t}\left[\frac{u}{r}\right]=\frac{2}{3}F(J_2)\left[Q-\frac{1}{2}(P+Q)\right]\phi(t)+\frac{1}{E}\frac{\partial[Q-\nu(P+Q)]}{\partial t}$$

$$=\frac{2}{3}F(J_2)\frac{(Q-P)}{2}\phi(t)+\frac{1}{E}\frac{\partial[Q-\nu(P+Q)]}{\partial t}$$

$$=-\frac{1}{3}F(J_2)[P-Q]\phi(t)+\frac{1}{E}\frac{\partial[(1-\nu)Q-\nu P]}{\partial t}$$

In the above expression J_2 becomes :

$$J_2=\frac{1}{6}[\Sigma(P-Q)^2]$$

$$=\frac{1}{6}[(P-Q)^2+0+(Q-P)^2]$$

$$=\frac{1}{3}(P-Q)^2.$$

‡ Johnson, A. E., Henderson, J., and Mathur, V. D. "Creep Under Changing Complex Stress Systems," THE ENGINEER 1958, 206, pages 209, 251, 287.

$F(J_2)$ is normally found for creep conditions to be of the form $F(J_2)=A(J_2)^{n/2}$ within those ranges of stress likely to be concerned with the requirements of practical design.

Accordingly the equations for α' and β' may further be rewritten :

$$\alpha'=\frac{\partial}{\partial t}\left(\frac{du}{dr}\right)=\frac{\frac{2}{3}A(P-Q)^{\overline{n+1}}}{(3)^{n/2}}\phi(t)+\frac{1}{E}\frac{\partial[P-2\nu Q]}{\partial t}$$

$$=\frac{2A(P-Q)^{\overline{n+1}}}{(3)^{(n+2)/2}}\phi(t)+\frac{1}{E}\frac{\partial[P-2\nu Q]}{\partial t}$$

$$\beta'=\frac{\partial\left(\frac{u}{r}\right)}{\partial t}=\frac{-\frac{1}{3}A(P-Q)^{\overline{n+1}}}{3^{n/2}}\phi(t)+\frac{1}{E}\frac{\partial[(1-\nu)Q-\nu P]}{\partial t}$$

$$=\frac{-A(P-Q)^{\overline{n+1}}}{3^{(n+2)/2}}\phi(t)+\frac{1}{E}\frac{\partial[(1-\nu)Q-\nu P]}{\partial t}$$

The equation of equilibrium is obtained by consideration of the equilibrium of an element cut out from the sphere by two concentric spherical surfaces of radii r, and $(r+\delta r)$ respectively, and by a circular cone with a small angle $\delta\psi$.

The equation of equilibrium then is :

$$Q\cdot\frac{\pi r}{2}dr(d\psi)^2=\frac{dP}{dr}\cdot\frac{\pi r^2}{4}dr(d\psi)^2+\frac{P\pi r}{2}dr(d\psi)^2$$

from which

$$Q=\frac{dP}{dr}\cdot\frac{r}{2}+P, \text{ or } (P-Q)=-\frac{r}{2}\frac{dP}{dr}=x \text{ say.}$$

This relation may also be written

$$Q=\frac{1}{2r}\frac{d(r^2P)}{dr}$$

or alternatively

$$\frac{d(r^2P)}{dr^2}=Q$$

For brevity put

$$\frac{A\phi(t)}{3^{(n+2)/2}}=G.$$

Then :

$$\alpha'=2Gx^{\overline{n+1}}+\frac{1}{E}\frac{\partial[P-2\nu Q]}{\partial t}$$

$$\beta'=-Gx^{\overline{n+1}}+\frac{1}{E}\frac{\partial[1-\nu)Q-\nu P]}{\partial t}.$$

By definition

$$\alpha'=\frac{\partial}{\partial r}(r\beta'), \text{ i.e. } (\alpha'-\beta')=r\frac{\partial\beta'}{\partial r}.$$

Now

$$(\alpha'-\beta')=3Gx^{\overline{n+1}}+\frac{1}{E}(1+\nu)\frac{\partial x}{\partial t}.$$

Also

$$\frac{r\partial\beta'}{\partial r}=-(n+1)Gx^n r\frac{\partial x}{\partial r}-\frac{1}{E}\frac{\partial}{\partial t}\left[-(1-\nu)r\frac{\partial Q}{\partial r}+\nu r\frac{\partial P}{\partial r}\right]$$

$$=-(n+1)Gx^n r\frac{\partial x}{\partial r}-\frac{1}{E}\frac{\partial}{\partial t}\left[(1-\nu)r\frac{\partial(P-Q)}{\partial r}+r\frac{\partial P}{\partial r}\{\nu-(1-\nu)\}\right]$$

$$=-(n+1)Gx^n r\frac{\partial x}{\partial r}-\frac{1}{E}\frac{\partial}{\partial t}\left[(1-\nu)r\frac{\partial x}{\partial r}+2x(1-2\nu)\right].$$

Hence

$$Gx^n\left[3x+(n+1)r\frac{\partial x}{\partial r}\right]=\frac{1}{E}\frac{\partial}{\partial r}\left[3x(\nu-1)-(1-\nu)r\frac{\partial x}{\partial r}\right]$$

$$=-\frac{(1-\nu)}{E}\frac{\partial}{\partial t}\left(3x+r\frac{\partial x}{\partial r}\right)$$

$$=-H\frac{\partial}{\partial t}\left(3x+r\frac{\partial x}{\partial r}\right) \text{ where } H=\frac{(1-\nu)}{E}.$$

$$\frac{\partial}{\partial r}\left[\frac{G}{H}r^3x^{\overline{n+1}}+r^3\frac{\partial x}{\partial t}\right]=0$$

or

$$\frac{\partial}{\partial r}\left[\frac{EA\phi(t)}{3^{(n+2)/2}(1-\nu)}r^3x^{\overline{n+1}}+r^3\frac{\partial x}{\partial t}\right]=0.$$

Integrating with respect to r we examine the form :

$$\left[\frac{EA\phi(t)r^3x^{\overline{n+1}}}{3^{(n+2)/2}(1-\nu)}+\frac{\partial(r^3x)}{\partial t}\right]=\frac{KEA\phi(t)}{3^{(n+1)/2}(1-\nu)}$$

where K is a constant.

Now let x_o and x_∞ (a finite value) be the values of x at zero and infinite time respectively. Then x_o must correspond to the elastic solution of Lamé which requires $x_o=-\frac{3}{2}\frac{B}{r^3}$ where B is a constant and equals $\frac{a^3b^3}{(b^3-a^3)}(p-q)$; x_∞ must correspond to the pure creep solution which ignores elastic strain and where $x_\infty^{\overline{n+1}}=K/r^3$. The solution for pure creep conditions is outlined in the Appendix.

In the equation immediately above :

$$K=\frac{(-1)^{\overline{n+1}}3^{\overline{n+1}}a^3b^3(p-q)^{\overline{n+1}}}{[2(n+1)\{b^{3/\overline{n+1}}-a^{3/\overline{n+1}}\}]^{\overline{n+1}}}.$$

Then we have :

$$x_o=\frac{-\frac{2}{3}B}{r^3}=-\frac{3}{2}\frac{a^3b^3(p-q)}{(b^3-a^3)r^3}$$

or

$$=\frac{-(b^3-a^3)x_o}{\frac{3}{2}(a^3b^3)(p-q)}=\frac{1}{r^3};$$

$$x_\infty^{\overline{n+1}}=\frac{(-1)^{\overline{n+1}}3^{\overline{n+1}}a^3b^3(p-q)^{\overline{n+1}}}{[2(n+1)\{b^{3/\overline{n+1}}-a^{3/\overline{n+1}}\}]^{\overline{n+1}}}\times\frac{(b^3-a^3)x_o}{(-1)\frac{3}{2}(a^3b^3)(p-q)}$$

$$=\frac{\left(\frac{3}{2}\right)^n(p-q)^n(b^3-a^3)x_o}{[(n+1)\{b^{3/\overline{n+1}}-a^{3/\overline{n+1}}\}]^{\overline{n+1}}}$$

or $x_\infty^{\overline{n+1}}=Cx_o$ for all values of x where

$$C=\frac{\left(\frac{3}{2}\right)^n(p-q)^n(b^3-a^3)}{[(n+1)\{b^{3/\overline{n+1}}-a^{3/\overline{n+1}}\}]^{\overline{n+1}}}.$$

Now referring again to the equation :

$$\left[\frac{EA\phi(t)r^3x^{\overline{n+1}}}{3^{(n+2)/2}(1-\nu)}+\frac{\partial(r^3x)}{\partial t}\right]=\frac{KEA\phi(t)}{(3)^{(n+2)/2}(1-\nu)}$$

where K is a constant.

If we write

$$\frac{EA\phi(t)}{(3)^{(n+2)/2}(1-\nu)}$$

as θ'_t we obtain : setting

$$K=r^3x_\infty^{\overline{n+1}}=\frac{(-1)^{\overline{n+1}}3^{\overline{n+1}}a^3b^3(p-q)^{\overline{n+1}}}{[2(n+1)\{b^{3/n+1}-a^{3/n+1}\}]^{\overline{n+1}}}$$

$$\left[x^{\overline{n+1}}-x_\infty^{\overline{n+1}}\right]\theta' t+\frac{\partial x}{\partial t}=0$$

or

$$\theta'_t dt=\frac{-d(x)}{[x^{\overline{n+1}}-Cx_o]} \text{ since } x_\infty^{\overline{n+1}}=Cx_o.$$

Integrating from time o to time t

$$\theta_t=\int_o^t\theta'_t dt=\int_o^t\frac{EA\phi(t)dt}{3^{(n+2)/2}(1-\nu)}=-\int_{x=x_o}^{x=x_t}\frac{dx}{[x^{\overline{n+1}}-Cx_o]}.$$

At $t=0$, x_t-x_o and the above equation is obviously satisfied, since $\int_o^t\phi(t)dt=0$. At $t\to\infty$ since $\int_o^t\phi(t)dt\to\infty$ and $x_\infty^{\overline{n+1}}-Cx_o$, the equation is satisfied by $x_t=x_\infty$, the right-hand side of the equation tending to infinite value.

The integral on the right-hand side may be evaluated graphically by plotting the function:

$$-\frac{1}{x^{\overline{n+1}}-Cx_o}$$

against x for various values of x between x_o and x_∞. Hence we can, for a specific radius, obtain the time t corresponding to a particular value of x, i.e. of $(P-Q)$, since the form of θ_t is known. From these data we can then obtain for each radius the value of x, i.e. of $(P-Q)$ at chosen specific times, say 10^2 hours, 10^3 hours, 10^4hours and 10^5 hours. Now since P is the radial stress :

$$-\frac{r}{2}\frac{\partial P}{\partial r}=x$$

$$\frac{\partial P}{\partial r}=\left(-\frac{2x}{r}\right)$$

$$P=\int\left(-\frac{2x}{r}\right)dr+D$$

where D is a constant.

To obtain P for a specific period of time, we can, therefore, proceed by graphical integration plotting the values $(-2x/r)$ obtained in the analysis of previous paragraphs against r, between the radius limits a and b. Since the value of P at the inside radius must be equal to $-p$ where p is the internal pressure and at the external radius to $-q$ where q is the external pressure, the full integration from $r=a$ to $r=b$ should yield the value $(p-q)$ which corresponds to $P=-q$ at $r=b$. Integration from $r=a$ to intermediate radii will, of course, give rise to the local values of P. We thus have P at each radius for a specific period and since $x=(P-Q)$, we can obtain Q.

The total strain rates at times t are :

$$\alpha'=\frac{2A(P-Q)^{\overline{n+1}}\phi(t)}{3^{(n+2)/2}}+\frac{1}{E}\frac{\partial[P-2\nu Q]}{\partial t}$$

$$\beta'=\frac{-A(P-Q)^{\overline{n+1}}\phi(t)}{3^{(n+2)/2}}+\frac{1}{E}\frac{\partial[(1-\nu)Q-\nu P]}{\partial t}.$$

We accordingly have all data necessary to determine rates α' and β', except the values $\partial P/\partial t$ and $\partial Q/\partial t$. These values must be obtained by plotting P and Q against t and measuring the slopes $\partial P/\partial t$ and $\partial Q/\partial t$. However, since a limited number of specific periods only is involved and these may be chosen conveniently for other reasons at logarithmic intervals corresponding to powers of 10, it is preferable to obtain $\partial P/\partial t$ and $\partial Q/\partial t$ from plots of log P and log Q against log time t, by using the identities :

$$\frac{\partial P}{\partial t}=\frac{\partial \log P}{\partial \log t}\times\frac{P}{t}$$

and

$$\frac{\partial Q}{\partial t}=\frac{\partial \log Q}{\partial \log t}\times\frac{Q}{t}.$$

The above procedure may be briefly summarised as follows :

(1) Evaluate

$$\theta_t=\int_o^t\frac{EA\phi(t)dt}{3^{(n+1)/2}(1-\nu)}.$$

(2) Compute B.

(3) Compute x_o for say six radii including a and b.

(4) Compute C.

(5) Compute x_∞ at corresponding radii.

(6) For each pair of values x_o and x_∞, taking initially about ten intermediate values of x and for these compute the value of

$$\theta_t=-\int_{x_o}^{x}\frac{dx}{[x^{\overline{n+1}}-Cx_o]}$$

by means of graphical integration.

(7) Obtain from plots of $x=(P-Q)$ against log t values of $(P-Q)$ for all radii corresponding to specific values of 10^2 hours, 10^3 hours, 10^4 hours and 10^5 hours.

(8) Compute values of $-(2x/r)$ for specific periods.

(9) Obtain values of P by graphical integration.

(10) From available values of x and P obtain values of Q.

Technical Contributors Section (*Continued*)

(11) Obtain values of $\partial P/\partial t$ and $\partial Q/\partial t$ from plots of log P, or log Q against log t.
(12) Compute values of strain rates α' and β'.

Conclusion

As a result of the above analysis, it is possible to predict the changes of stress and strain, occurring with time, in a spherical pressure vessel under the conditions stated.

APPENDIX

Solution for the Case in Which Elastic Strains are Considered Trivial Compared with Creep Strains

As for the general case the equilibrium relation is :

$$(P-Q)=-(r/2)(dP/dr)$$

or

$$Q=\frac{1}{2r}\frac{d(r^2P)}{dr}$$

or

$$Q=\frac{d(r^3P)}{dr^3}$$

For this special case the expressions for the creep rates become :

$$\alpha'=\frac{2A(P-Q)^{\overline{n+1}}\phi(t)}{3^{(n+2)/2}}$$

$$\beta'=\frac{-A(P-Q)^{\overline{n+1}}\phi(t)}{3^{(n+2)/2}}$$

From consideration of the constant density which hold for conditions of pure creep strain:

$$\beta'=a/r^3\beta'_a=b/r^3\beta'_b$$

(where β'_a and β'_b apply to radii a and b).
That is :

$$\frac{-A(P-Q)^{\overline{n+1}}\phi(t)}{3^{(n+2)/2}}=\left(\frac{a}{r}\right)^3\left[\frac{-A(P_a-Q_a)^{\overline{n+1}}\phi(t)}{3^{(n+2)/2}}\right]$$

$$=\left(\frac{b}{r}\right)^3\left[\frac{-A(P_b-Q_b)^{\overline{n+1}}\phi(t)}{3^{(n+2)/2}}\right].$$

Thus

$$(P-Q)=\left(\frac{a}{r}\right)^{3/\overline{n+1}}(P_a-Q_a)=\left(\frac{b}{r}\right)^{3/\overline{n+1}}(P_b-Q_b).$$

Substituting the equilibrium equation $P-Q=-(r/2)(dP/dr)$ into the above relationship leads to :

$$\left(\frac{a}{r}\right)^{3/\overline{n+1}}(P_a-Q_a)+\frac{r}{2}\frac{dP}{dr}=0$$

or

$$\frac{1}{r}\left(\frac{a}{r}\right)^{3/\overline{n+1}}(P_a-Q_a)+\frac{1}{2}\frac{dP}{dr}=0.$$

Upon integration this relation becomes :

$$\frac{-(n+1)}{3}(P_a-Q_a)\left(\frac{a}{r}\right)^{3/n+1}+\frac{1}{2}P=C$$

$P=-q$ at $r=b$.

Thus

$$C=\frac{-(n+1)}{3}(P_a-Q_a)\left(\frac{a}{b}\right)^{3/n+1}-\frac{q}{2}$$

and

$$\frac{P}{2}=\frac{(n+1)}{3}(P_a-Q_a)\left(\frac{a}{r}\right)^{3/n+1}$$

$$-\frac{(n+1)}{3}(P_a-Q_a)\left(\frac{a}{r}\right)^{3/n+1}-\frac{q}{2}$$

$$=\frac{(n+1)}{3}(P_a-Q_a)\left[\left(\frac{a}{r}\right)^{3/n+1}-\left(\frac{a}{b}\right)^{3/n+1}\right]-\frac{q}{2}.$$

Since $P=-p$ at $r=a$.

$$\frac{(n+1)}{3}(P_a-Q_a)=\frac{-\frac{(p-q)}{2}}{\left[1-\left(\frac{a}{b}\right)^{3/n+1}\right]}$$

and

$$\frac{P}{2}=\frac{-\frac{(p-q)}{2}}{\left[1-\left(\frac{a}{b}\right)^{3/n+1}\right]}\left[\left(\frac{a}{r}\right)^{3/n+1}-\left(\frac{a}{b}\right)^{3/n+1}\right]-\frac{q}{2}$$

$$P=-\frac{\left[\left(\frac{a}{r}\right)^{3/n+1}-\left(\frac{a}{b}\right)^{3/n+1}\right]-q\left[1-\left(\frac{a}{r}\right)^{3/n+1}\right]}{\left[1-\left(\frac{a}{b}\right)^{3/n+1}\right]}$$

$$=-p\frac{\left[\left(\frac{ab}{r}\right)^{3/n+1}-a^{3/n+1}\right]-q\left[b^{3/n+1}-\left(\frac{ab}{r}\right)^{3/n+1}\right]}{[b^{3/n+1}-a^{3/n+1}]}$$

$$=\frac{1}{[b^{3/n+1}-a^{3/n+1}]}\left[(a^{3/n+1}p-b^{3/n+1}q)-\left(\frac{ab}{r}\right)^{3/n+1}(p-q)\right].$$

Now we have

$$(P-Q)=\left(\frac{a}{r}\right)^{3/n+1}(P_a-Q_a)$$

$$=\left(\frac{a}{r}\right)^{3/n+1}\left[\frac{-3(p-q)}{2(n+1)\left[1-\left(\frac{a}{b}\right)^{3/n+1}\right]}\right]$$

$$=\frac{-3}{2(n+1)}\frac{p-q}{[b^{3/n+1}-a^{3/n+1}]}\left(\frac{ab}{r}\right)^{3/n+1}$$

and thus :

$$Q=\frac{1}{[b^{3/n+1}-a^{3/n+1}]}\left[(a^{3/n+1}p-b^{3/n+1}q)-\left(\frac{ab}{r}\right)^{3/n+1}(p-q)+\frac{3}{2(n+1)}(p-q)\left(\frac{ab}{r}\right)^{3/n+1}\right]$$

$$=\frac{1}{[b^{3/n+1}-a^{3/n+1}]}\left[(a^{3/n+1}p-b^{3/n+1}q)-\left(\frac{ab}{r}\right)^{3/n+1}\frac{(2n-1)}{2(n+1)}(p-q)\right]$$

$$(P-Q)=\underset{\infty}{x}=\frac{\frac{-3}{2(n+1)}\left(\frac{ab}{r}\right)^{3/n+1}(p-q)}{[b^{3/n+1}-a^{3/n+1}]}$$

and

$$\underset{\infty}{x}^{\overline{n+1}}=\frac{(-1)^{\overline{n+1}}3^{n+1}a^3b^3(p-q)^{\overline{n+1}}\frac{1}{r^3}}{[2(n+1)\{b^{3/n+1}-a^{3/n+1}\}]^{\overline{n+1}}},$$

a relation which is used in the main body of the text.

The strain rates for conditions of pure creep are then given as below :

$$\alpha'=\frac{2A(P-Q)^{\overline{n+1}}\phi(t)}{(3)^{(n+2)/2}}$$

$$=\frac{2A(-1)^{\overline{n+1}}3^{n+1}a^3b^3(p-q)^{\overline{n+1}}\frac{1}{r^3}}{(3)^{(n+2)/2}[2(n+1)\{b^{3/n+1}-a^{3/n+1}\}]^{\overline{n+1}}}$$

$$=\frac{2A(-1)^{\overline{n+1}}3^{(n/2)}a^3b^3(p-q)^{\overline{n+1}}\frac{1}{r^3}}{[2(n+1)\{b^{3/n+1}-a^{3/n+1}\}]^{\overline{n+1}}}$$

and of course :

$$\beta'=-\frac{\alpha'}{2}=\frac{-A(-1)^{\overline{n+1}}3^{n/2}a^3b^3(p-q)^{\overline{n+1}}\frac{1}{r^3}}{[2(n+1)\{b^{3/n+1}-a^{3/n+1}\}]^{\overline{n+1}}}.$$

Spring Mounting for a Large Camera

By J. A. MACINANTE*

A description is given of a spring mounting designed to isolate a 7-ton camera from structural vibration. Because of the low frequency of the vibration, which had rendered the camera unusable on its usual type of mounting, the values specified for the natural frequencies were 1 c/s in the horizontal (lower coupled) rocking modes and 2 c/s in the vertical mode. These values were attained through the use of twelve helical compression springs in three groups of four springs. The effectiveness of the mounting has been proved in vibration and photographic tests.

ALTHOUGH spring mountings have been used to isolate a wide variety of sensitive instruments from building vibration, their use for supporting cameras is unusual. Hence this description of a successful spring mounting for an exceptionally large camera may be of interest, especially as the low frequency of the site vibration made very soft springing necessary and the mounting of a large and valuable equipment in such a way that it could be "rocked like a boat" was approached with some trepidation.

The camera, a Klimsch "Commodore," was of the type used for photolithography and map copying. It weighed 7 tons and was 30ft long, 10ft high and 10ft wide at the plate end (plate size 50in by 50in). Because such cameras must be vibration-free for good reproduction of fine linework they are installed preferably in basement rooms and remote from sources of vibration. For convenience of work flow, and because the basement contained printing machinery, John Sands Pty., Ltd., wanted to instal one of these cameras on an upper floor of their Sydney factory. The camera was placed at first on the rubber isolators normally supplied with it. Such isolators are understood to have proved satisfactory in installations of these cameras throughout the world. However, because of the nature of the vibration at this particular location these isolators proved quite unsatisfactory.

An experimental analysis of the floor vibration showed that the lowest predominant frequency of vibration was in the vicinity of 3 c/s, and this occurred in the horizontal-y direction perpendicular to the optical axis of the camera (see Fig. 1). This frequency was identified at a number of places throughout the building, and since there was no source of vibration operating at this frequency in the building or in the neighbourhood, it was assumed that this was a natural frequency of the structure. It was recommended that a spring mounting be provided, having a natural frequency of about 1 c/s

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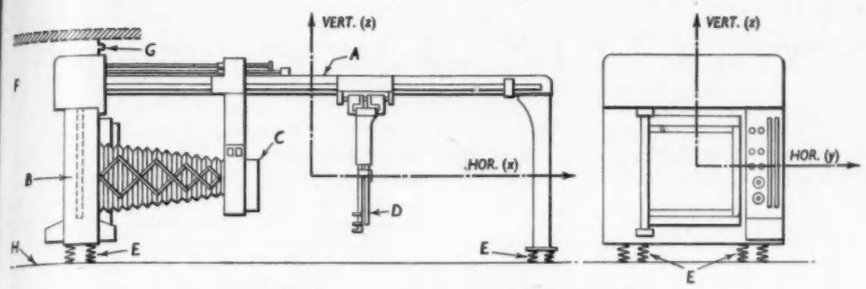

A—Camera body.
B—Plate.
C—Lens.
D—Copyboard.
E—Spring supports.
F—Dark room.
G—Dark-room bellows.
H—Floor beam.

Fig. 1—Diagram of camera

in the lower horizontal rocking modes. In the vertical direction, a natural frequency of about 2 c/s was proposed, corresponding to a static deflection of about 2½in. The details were designed by Mr. P. D. Isaacs of Macdonald, Wagner and Priddle, consulting engineers, Sydney. Twelve springs were used, in two groups of four springs at the plate end of the camera (Fig. 1) and one group of four at the foot of the column at the other end of the camera (Fig. 2). The springs were of ⅜in square section and 5½in outside diameter.

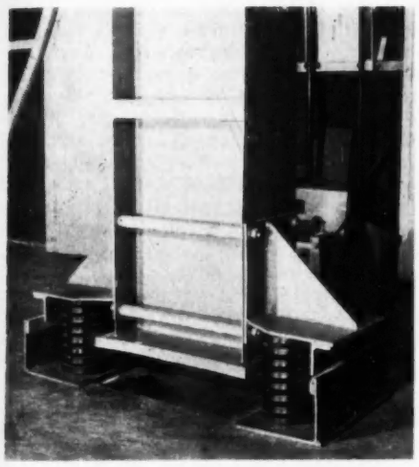

Fig. 2—Close-up view of spring-support

Tests

The following series of tests were made :

Natural Frequencies.—In the various natural modes, the frequency of manually-sustained vibration was found by visual counting and stopwatch timing over at least 20 cycles. The results, which were observed for convenience before affixing the dark-room bellows, are given below. Subsequent observations showed that a small increase in the frequencies caused by these bellows was unimportant.

Mode of Vibration (see Fig. 1)	Natural frequency
	c/s
Vertical (*z*)...	2·0
Rotation in *yz* plane...	0·7, 3·1
Rotation in *xz* plane...	1·4, 2·2
Rotation in *xy* plane...	2·3

The calculated values of frequencies in both simple and coupled modes agreed closely with the observed values except that somewhat lower values had been expected for the higher coupled modes. In particular, the values for the lower rocking modes (0·7, 1·4 c/s) and for the vertical mode (2·0 c/s) satisfied the specified requirements. In view of the 3·1 c/s for the higher mode in the *yz* plane, it was fortuitous that there was no trouble from excitation in this mode.

Vibration Transmission.—The vibration of the camera was observed during normal factory activities and, for test purposes, it was observed while a person jumped heavily on the floor beam at the plate-end of the camera. The typical oscillograph traces given in Fig. 3 illustrate the effectiveness of

Trace 1—Vibration at floor beam with person jumping on floor beam.
Trace 2—Simultaneous record of vibration at plate end of camera.

Fig. 3—Oscillograph traces

the isolation. Trace 1 shows the floor vibration caused by a person jumping. Trace 2, taken simultaneously at the plate-end of the camera and with the same magnification as trace 1, shows that the high-frequency vibration was eliminated by the springs while the camera " bounced " continuously in a natural mode. This free motion could have been suppressed by damping but this was found to be unnecessary. The example relates to the vertical vibration ; similar results were recorded in the horizontal directions.

Other observations confirmed that the plate, lens, and copy-board vibrated in phase. Some high-frequency response to jumping was detected with sensitive vibration pick-ups at some positions on the camera, but photographic tests proved that this response was unimportant.

Photographic Tests.—As an overall performance test, the camera was used to photograph a scale having 100 lines spaced 0·1mm (0·004in) apart. Four exposures were made, two under normal conditions of the factory activity and the others while two persons repeatedly jumped in unison on the floor beam. All exposures were of thirty seconds duration and at 1 : 1 magnification. No blurring of the lines could be discerned on any of the negatives.

The camera has been in use on the spring mounting for eighteen months and has given completely satisfactory results.

Acknowledgments

The details of this mounting are published with the kind permission of John Sands Pty., Ltd., Druitt Street, Sydney ; of Middows Brothers Pty., Ltd., Clarence Street, Sydney, the Australian representatives of Klimsch and Co., Frankfurt, Germany ; and of the consulting engineers Macdonald, Wagner and Priddle, Young Street, Sydney. The very able assistance of Mr. H. Ruth, who installed the camera for Klimsch and Co., was much appreciated. The vibration tests and analyses were made with the assistance of the author's colleagues, J. Waldersee and K. O'Toole of the Division of Metrology, Commonwealth Scientific and Industrial Research Organization.

Measuring the True Static Pressure in a Moving Fluid

By J. D. JACKSON*

A procedure is suggested for obtaining the static pressure in a ducted flow by means other than the use of a static hole or a movable wall segment. The method depends upon the fact that under certain conditions it is possible to obtain both the velocity and the total pressure at a point in a fluid extremely accurately, and hence the static pressure can be deduced from them. It is concluded that the procedure suggested could lead to much-needed information concerning the accuracy of static pressure measurement by means of static holes.

THE static pressure in a moving fluid is usually measured by means of a static hole, either in a probe or on the wall of a duct. Since such a hole causes a disturbance in a flow, there is always some error associated with static pressure measurement by means of a static hole. In order to be able to correct these errors, various experimenters have carried out tests involving static holes of various sizes and shapes situated in regions of nominally constant pressure. In this way, relative errors have been measured and attempts have been made to estimate absolute errors by extrapolating the relative error curves down to zero hole size.

Due to the practical difficulty of producing good quality holes of very small dimensions, it has proved to be very difficult to establish the precise shapes of the relative error curves for small hole sizes. It is not surprising, therefore, that due to differing interpretations of the extrapolation process, there still is some disagreement as to the form of the absolute error curve. Furthermore, it would appear that a rigorous justification of the assumption that error tends to zero as hole size tends to zero still remains to be given. It is apparent, therefore, that even though a tentative correction to the reading given by a static hole can be made on the basis of available error data, the corrected pressure might still be unreliable. Since the need for extremely accurate measurement of static pressure does sometimes arise in modern engineering practice, for instance in the estimation of turbine power plant performance, it is obvious that some alternative approach to the problem of static hole error measurement would be desirable.

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Technical Contributors Section (*Continued*)

Possible Alternative Methods of Static Pressure Measurement

The Direct Measurement of Pressure by Mechanical Means.—An obvious alternative to the static hole is the direct measurement of pressure on a movable segment on the wall of a duct by some accurate mechanical means. A suitable arrangement for doing this must satisfy the following requirements :

(*a*) The movable segment must be of the null reading diaphragm type, since the wall must be continuous if there is to be no disturbance to the flow.

(*b*) The arrangement to be used must be of extremely high sensitivity.

(*c*) It must be designed to be able to withstand shear force effects without interfering with normal pressure force measurement.

(*d*) Since the movable wall segment will inevitably have to be of reasonably large dimensions, it will have to be used in a large tunnel in a region of zero pressure gradient.

It is apparent that although such a scheme is theoretically possible, many severe practical difficulties are involved. After consideration of these difficulties, it has been concluded that the direct measurement of static pressure by means of a movable wall segment is unlikely to yield results of sufficient accuracy to permit a reliable assessment of absolute static hole errors.

In the following section, a possible alternative approach is suggested.

An Estimation of Static Pressure from Accurately Determined Values of Total Pressure and Dynamic Pressure.—The method discussed in this section is based upon the idea that if both the velocity and total pressure at a point in a moving fluid can be very accurately established, the static pressure can be deduced from them. To assess the feasibility of such a scheme, it is necessary therefore to consider whether it is possible

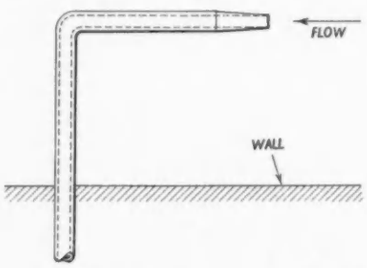


Fig. 1—A sharp-nosed, forward-facing Pitot tube

to establish both the total pressure and the velocity in a moving fluid to the required accuracy.

The total pressure in a uniform flow can be established to a very high degree of accuracy using a calibrated, forward-facing Pitot probe. In the course of some recent probe error tests, a Pitot probe of the type shown in Fig. 1 has been calibrated by using it to measure the total pressure on the axis of the throat of a well-designed bellmouth air intake (see Fig. 2). In such a situation, the true total pressure is the ambient pressure and so the registered pressure, measured relative to the ambient pressure, gives the probe error directly.

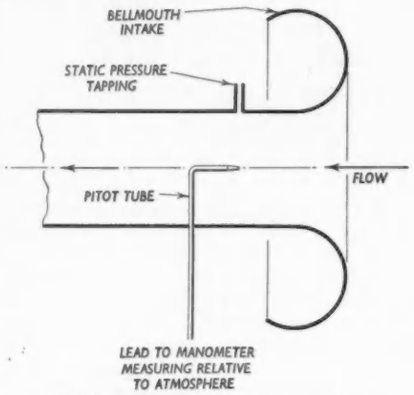


Fig. 2—Bellmouth intake arrangement

It was found that the design shown in Fig. 1 gave a total pressure reading which differed from the true value by less than 0·03 per cent. It is apparent, therefore, that even without calibrating, the accurate measurement of total pressure in a uniform flow presents little difficulty.

The accurate measurement of velocity is, however, somewhat more difficult. Methods not involving the use of a static hole which warrant consideration are :

(*a*) Optical methods involving establishing the velocity of a particle moving with a fluid.

(*b*) Towing or whirling arm methods.

(*c*) Methods involving knowing accurately the shape of the velocity profile in particular ducted water flows where an accurate direct measurement of mean velocity is possible by collecting and weighing.

Of these three methods, the last one appears to be the most promising. One interesting possibility in this connection is to make use of the exact solution of the Navier-Stokes equations for fully developed laminar flow in circular tubes. For such a flow the maximum velocity is twice the mean velocity and hence, if the latter can be obtained accurately, the maximum velocity can also be found. If a liquid is used as the working fluid, the mass flow and hence the mean velocity, can be found very accurately by collecting and weighing. If the total pressure on the axis of symmetry were measured using a calibrated Pitot probe (the calibration having been carried out under similar tube Reynolds number conditions using the method described earlier) then the static pressure for the same flow conditions with no probe present could be calculated.

This pressure could then be compared with that obtained by static holes of various sizes at the same section, and absolute values of static hole errors could be directly obtained. It is obvious that the accuracy of the pressure measurements in an experiment of the type just described would be greatly increased by using a highly viscous liquid as the working fluid.

The main need for accurate static pressure measurement arises in practice in flows which are turbulent, and hence, although an experiment of the type just considered would be of some academic interest, an alternative scheme involving a turbulent boundary layer is desirable. In this connection, a bellmouth intake arrangement of the type shown in Fig. 2 could be useful. Designs for bellmouth intakes having extremely uniform throat velocity distributions are available. The presence of a turbulent boundary layer at the throat in a bellmouth can be ensured by the use of small boundary layer trips. Thus it should be possible to obtain a ducted turbulent flow with a value of V_{max}/V_{mean} close to 1, having a very symmetrical velocity distribution.

Using the bellmouth as an air intake, the value of V_{max}/V_{mean} could be accurately determined by conventional methods involving traversing with a Pitot probe of the type shown in Fig. 1 and measurement of the static pressure at the traversing section using wall static holes (a check on the uniformity of static pressure across the flow could also be carried out using a conventional static pressure probe).

In the uniform part of the flow, total pressure probe error would be directly measured as described earlier, and in the boundary layer, the error could be assumed to be the same, since previous work has established that the boundary layer displacement error for a sharp-nosed, forward-facing probe is small. As the flow in the boundary layer will represent only a very small fraction of the total flow, a small error in total pressure in the boundary layer will have a very much reduced effect on the estimated ratio of maximum velocity to mean velocity. Also, a small error in static pressure measurement at the traversing section would have a negligible effect on the estimated value of the ratio of maximum to mean velocity.

Once V_{max}/V_{mean} is established to a high degree of accuracy, it could be used for the purpose of estimating the maximum velocity from a measured mean velocity. The latter could be obtained by collecting and weighing if the intake were to be used under similar Reynolds number conditions with a liquid as the working fluid (in this case water would probably be a suitable liquid). The total pressure on the axis could be measured accurately using the Pitot probe calibrated in the earlier air tests, and thus the static pressure on the axis could be obtained. The estimation of the wall static pressure from the stream static pressure could be carried out making use of the information about static pressure variation across the flow obtained by traversing in the air tests. The wall static pressure finally deduced could be compared with that measured by wall static tappings of various sizes under the same flow conditions, and thus absolute static hole errors could be determined.

Conclusions

Whilst it is obvious that extreme care would have to be taken with experimental techniques, if the procedure described in the preceding paragraphs were to yield reliable results, it is nevertheless concluded that the method described is feasible and could lead to much-needed information about the absolute level of static hole errors.

Inauguration of CANTAT Cable

The final splice in the CANTAT telephone cable was made fifty miles out from Hampden, Newfoundland, on November 22, 1961, and on December 19 the first call over the cable was made by Her Majesty the Queen from Buckingham Palace, speaking to the Canadian Prime Minister, Mr. J. G. Diefenbaker, in Ottawa.

THE cable known as CANTAT is the first link in the Commonwealth telephone cable system. Its trans-Atlantic section extends from Oban in Scotland to Corner Brook, Newfoundland, 2400 miles by submarine cable including 72 miles carried underground across Newfoundland from the landing point at Hampden to Corner Brook. A second submarine system covers the 470 miles from Corner Brook to Grosses Roches on the Canadian mainland, whence 425 miles of microwave links connect with Montreal. Financing and laying of the cable have been the joint responsibility of Cable and Wireless Ltd., and the Canadian Overseas Telecommunication Corporation.

Details of the lightweight unarmoured coaxial cable used in the deep-water sections of this project, manufactured by Submarine Cables Ltd., and of the two-way repeaters and laying gear, were given in THE ENGINEER of February 3, 1961, page 178, and March 31, 1961, page 486. We illustrate the launching of a repeater during the laying operations by H.M.T.S. " Monarch," showing it travelling through the trough which by-passes the laying gear, and entering the water followed by the parachute which retards its descent. The method of laying repeaters by by-passing the normal gear was developed by the British Post Office for dealing with comparatively long and heavy rigid units while the ship continues ahead at about 1½ knots. All repeaters for the Oban–Corner Brook section were manufactured by Standard Telephones and Cables Ltd. Equalisers in similar housings, wired up in the ship on the basis of measurements made as laying proceeded, were inserted after every twelve repeater sections.

The trans-Atlantic section from Oban to Corner Brook is designed to provide sixty telephone circuits, at 4 kc/s spacing, to C.C.I.T.T. standards, and planned so that these could form part of trans-global circuits extending over 16,000 miles. An important design objective of the submarine systems was that the 60–108 kc/s group bands should be clear of spurious frequencies to ensure that the available bandwidth could be used without restriction. This was done so that high-efficiency channel equipment, using 3 kc/s spaced channels, could be used on the system should the need for more circuits arise. Using this channel equipment the system capacity could be increased to eighty telephone channels and it is planned to effect such an increase in about one year.

The Oban–Corner Brook system, which is equipped with ninety submerged repeaters and eight submerged equalisers, is at present the longest single submarine cable in the world equipped for two-way operation. On the underground section across Newfoundland, for which the cable was manufactured by Standard Telephones and Cables Ltd., the four repeaters are laid in ponds or wet ground to restrict temperature rise under working conditions. Additional electrical screening is included in this section.

The Corner Brook–Grosses Roches submarine cable system provides for ten 60–108 kc/s groups in each direction of transmission. System capacity using conventional 4 kc/s spaced channel equipment is thus 120 circuits. The system is equipped with twenty repeaters and three equalisers, two of the equalisers being incorporated with two of the repeaters. The cable, manufactured by Submarine Cables Ltd., has a coaxial structure using a solid copper inner conductor of external diameter 0·26in. A polythene compound is extruded over the inner conductor to a diameter of 0·935in. The outer conductor consists of a layer of six annealed copper tapes applied uniformly over the polythene insulant and an overall copper binder tape. Conventional steel wire armouring is used throughout this section.

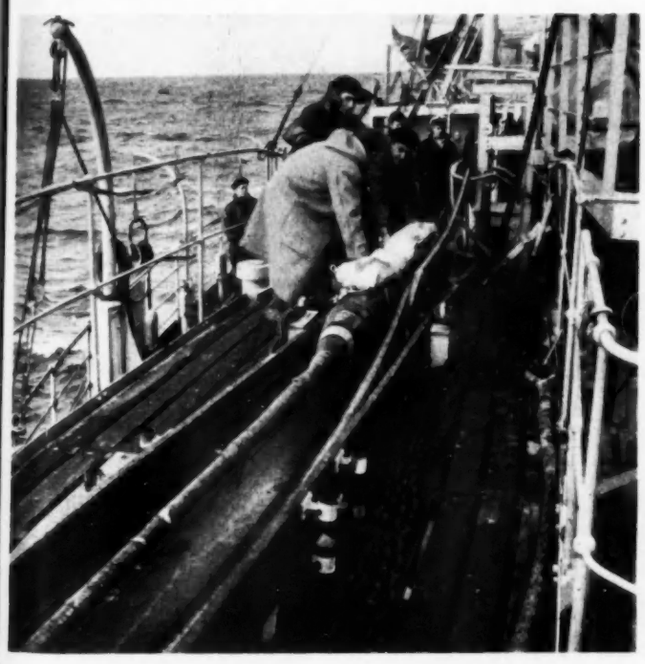
Frequency translation and power equipment for the Corner Brook–Grosses Roches section have been supplied by the Telecommunication Transmission Department, Telecommunications Division, Associated Electrical Industries Ltd. Terminal equipment is duplicated and continuously monitors the system by means of test signals. Automatic periodical monitoring of that part of the apparatus on " standby " also takes place. Two power units connected in series are provided at each terminal and are so arranged that on the failure of any unit, the load is automatically redistributed among the remaining three. A further standby unit is available at each end. A supply of 430mA d.c., closely regulated to within ±1 per cent, is maintained irrespective of supply voltage to the twenty repeaters, which are connected in series. At one end of the cable the supply is at 880V positive, at the other, 880V negative, with respect to earth, making a total of 1760V.

Similar arrangements apply to the power for the Oban–Corner Brook system, but here the total normal voltage required is about 10,000V.

The 60–108 kc/s group bands of the submarine sections and the Canadian and U.K. (London–Oban) inland sections are joined together at the intermediate stations to form the overall system groups on which are routed the London–Montreal telephone circuits.

Other facilities provided by the CANTAT system are telegraph circuits, and programme circuits giving bandwidths from 3·4 to 10 kc/s. The programme circuits may be used for data transmission or cable-film transmission. As a result of opening the cable the number of public telephone circuits between London and Montreal is nearly doubled, and there are ten more circuits between London and New York via Montreal. The number of London–Montreal telex circuits is increased from eleven to twenty.

The illustrations of launching a repeater which accompany this article are Crown copyright.



(Left)—A repeater approaches the stern sheaves during the laying of the CANTAT cable by H.M.T.S. "Monarch." (Right)—The repeater leaves the stern sheaves and the parachute bag falls clear

Problems of Commuter Traffic in Conurbations

THE PRESENT SITUATION AND THE FUTURE

By ANTHONY BULL, O.B.E., M.A., M.Inst.T.*

Below we print an extract from the Forty-eighth Thomas Hawksley Lecture, which was presented before the Institution of Mechanical Engineers on December 13, 1961. *The author first reviewed the existing situation and provided a number of statistics illustrating in particular the morning and evening peak commuter flows into and out of London, and the changes which have occurred since* 1950. *He referred also to the Greater London Road Plan of* circa 1945 *and to the London Plan Working Party proposed railway system of* 1949. *He then went on to consider the future development of London's transport system, and it is this section which we reprint. He supported the Nugent Plan for roads, costing* £200 *millions over twenty years, and the expenditure over an equal interval of time of about* £120 *millions on the extension and improvement of underground and surface railways.*

Future Structure of the City

THE present state of commuter traffic in London—and a similar pattern may be seen in other large conurbations—may be summarised in this way. Urban road and rail facilities are inadequate for the movement, at reasonable speed and in comfort, of the existing commuter traffic at the height of the peak periods. Redevelopment of the inner central area is causing an increasing commuter traffic. This is the problem to be solved.

The first necessary step is to measure the problem. Figures of movement of commuter traffic in and out of London are known (Table I).

TABLE I—*Distribution of passenger traffic into Central London during the morning peak period* (7.0 *a.m.*–10.0 *a.m.*) 1960 *compared with* 1950
(*Courtesy of London Transport Executive*)

	1950		1960		
	Thousands	Percentage of total	Thousands	Percentage of total	Standardised (1950=100)
Road services ...	295	24·7	215	16·6	73
Underground ...	461	38·7	506	39·0	110
British Railways	381	32·0	453	35·0	119
Total public transport	1,137	95·4	1,174	90·6	103
Private transport*	55	4·6	122	9·4	222
Total	1,192	100·0	1,296	100·0	109

* Cars, motor-cycles, scooters and pedal cycles.

The location of the inhabitants in their houses and at their work places is known. What is not known is the origin and destination of the individual movements which produce the total figures. Implementing a recommendation of the Nugent Committee, the Ministry of Transport and the London County Council, with the assistance of consulting engineers, have arranged for the carrying out of a comprehensive survey of the origin and destination of traffic in the London area and the present journey times.

Having determined the weight of the flows of traffic moving or desiring to move along particular routes, it then becomes possible to make a comprehensive plan for their movement.

The Royal Commission on Local Government in Greater London (1957–60) came to the conclusion that London's traffic problem could not be solved under the present administrative machinery and that it was necessary for one authority to be responsible for traffic planning and management (as described in the report and as is being carried out by the London Traffic Management Unit of the Ministry of Transport) and for the construction, improvement, maintenance and lighting of all main roads in Greater London. The establishment of machinery of the character proposed by the Royal Commission would greatly facilitate the planning of London as a living whole, of which the bones are the buildings, and the arteries are the roads and the railways. Hitherto, for historical and technical reasons, these two essential and interdependent parts of the urban body have too often been considered separately and treated independently.

It is possible to suggest some of the principal lines along which development should proceed; what is said here will require modification and change as more complete information becomes available and as techniques develop.

Town Planning.—It will be the task of the Regional Planning Authority—and ultimately contemporary London may require an authority whose responsibility is geographically wider than that of the Greater London Council proposed by the Royal Commission—to plan the location and development of commercial and industrial undertakings and residential and other accommodation in conjunction with the development of transport facilities both by road and by rail, so that the transport facilities are fully adequate to convey those who need to move to and from and within the city. Past experience and present prudence both suggest that some margin of capacity should be provided, where this can be done at reasonable cost.

It is desirable on social and economic grounds that a substantial proportion of workers should live near their place of work, within walking distance or a short ride by public transport. Development, such as the Barbican scheme, providing residential accommodation close to the offices in the City of London, is wholly to be welcomed. Office accommodation, on a considerable scale, is being built in suburban and outer London

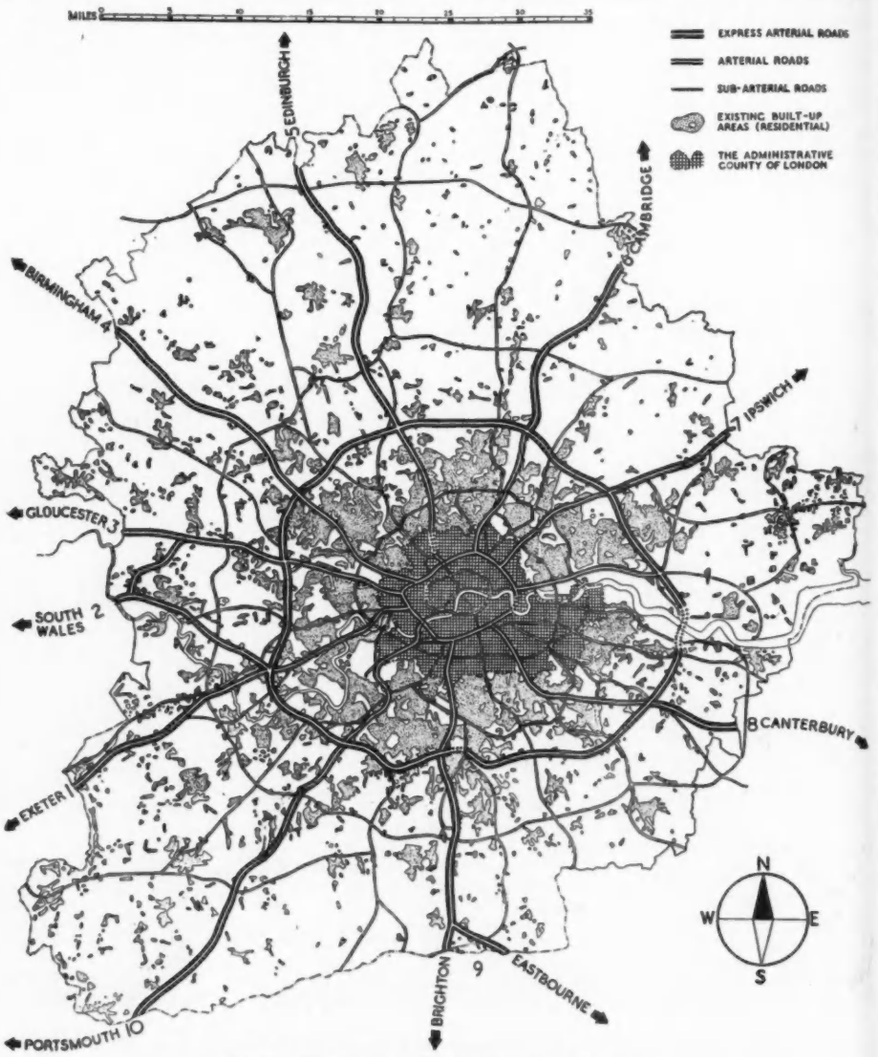


Fig. 1—Greater London Plan: proposed road system

* Member of the London Transport Executive.

areas. But valuable as these developments are in reducing peak travel, they will not preclude the need to make proper provision for the very large number of people who need or who choose (for good reasons) to reside in the outer areas and come to work in the central area of the city.

Future Development of the Road System.—To provide a road system such as that envisaged under the Greater London Plan (Fig. 1), which would necessarily include radial and ring urban motorways and parking facilities adequate for all the commuters who might wish to come into the central area by private car would be prohibitively expensive, in money terms, in the destruction of amenity and of the city: and I believe, with Lewis Mumford, that the city as a political, economic and cultural centre, is a living and unitary organism which its citizens must preserve.

Limited road improvements of the nature and on the scale proposed by the Nugent Committee (continuing beyond the twenty years of the terms of reference of the Committee—a short time in the planning and life of a city) appear to be practicable without doing disproportionate damage to the amenities of the city. These improvements must be so designed as to provide conditions in which the public passenger road undertakings can provide a regular and speedy service of high-capacity vehicles; such freight as must be moved by road must be accommodated; and a reasonably quick journey should be made possible for private means of transport to the extent that the admission and movement of private transport within the central area can be justified on economic and social grounds. The Minister of Transport has appointed Mr. Colin Buchanan to undertake a study of the development problems of roads and traffic in urban areas and their influence on the urban environment. Mr. Buchanan is to be assisted by a Steering Group, of which Sir Geoffrey Crowther is Chairman.

Traffic Engineering.—In the development of road improvements, traffic engineers can play a major part in the planning of the physical improvements, in the methods of control and use of the whole road system, including the use of existing streets. Although "traffic engineering" is not a wholly appropriate description for this relatively new science, it does indicate the essential quality that is concerned with movement. It is important that traffic engineering should not be regarded as exclusively the concern of civil and highway engineers. The techniques of traffic engineering are in a preliminary stage of development. I suggest that a major contribution to this development can be made by mechanical engineers who have been trained to appreciate and solve, in accordance with scientific principles, many of the problems involved in movement. Electrical engineers, statisticians and police can also make an important contribution to the development and use of traffic engineering techniques. An indication of possible developments in this field is afforded by the work of Mr. Henry A. Barnes, Traffic and Transit Commissioner of the City of Baltimore where, amongst many other applications of traffic engineering, the traffic signals on important through roads are controlled by computers working on the actual minute-to-minute flow through successive street junctions.

Parking.—In parallel with the road improvements, off-street parking must be provided for such volume of long-term parking of private vehicles as can be accommodated at an economic price. Short-term parking can properly be provided by parking meters. A calculation can be made which shows that the figure of 6d. an hour under the present parking meter scheme represents less than the equivalent rental value in central London of the road space occupied. There seems to be no case for allowing parking of private vehicles in cities on the streets or off the streets at other than an economic price. It is difficult to see that there is any case for parking meter receipts to be used to subsidise the provision of off-street parking.

Mechanical engineers can make a valuable contribution in the development of mechanical parking devices for off-street parking.

It is of great importance that parking facilities should not be provided on a scale so large that they attract into the city private cars to a number beyond the capacity of the road system. It is notable that in New York it has been decided that parking facilities shall not be provided in new offices because there is no room in the streets for the additional traffic which would be generated by additional parking facilities.

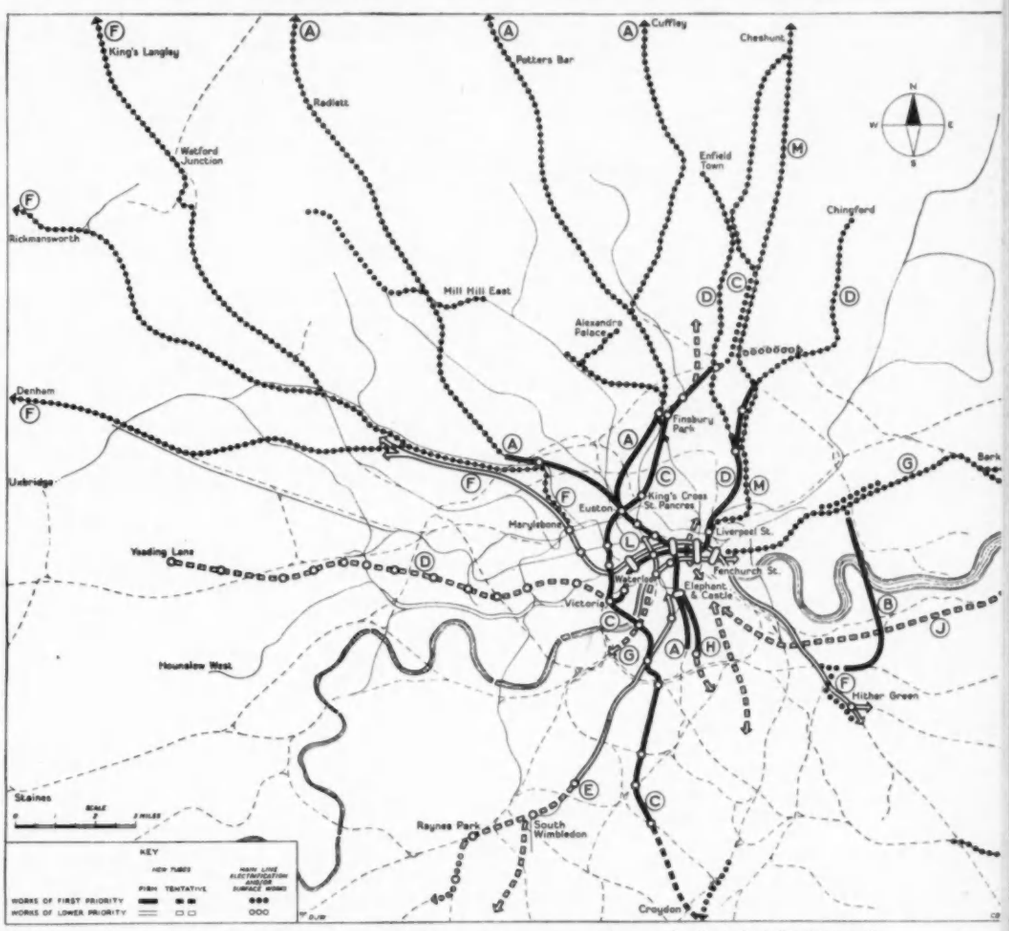


Fig. 2—London Plan Working Party: proposed railway system; new tubes, main line electrification and surface works

Effect of Road Improvements on Commuter Traffic

By improvement of the road system, employing all the devices made available by sound planning and traffic engineering; by a continuation in the improvement of the design of road vehicles, to which mechanical engineers have made so great a contribution; by providing special facilities for public passenger transport (in some overseas cities special lanes are reserved for public service vehicles and these vehicles are allowed to make right-hand or left-hand turns where they are forbidden for other traffic); by control of the parking of private cars on the streets; by restrictions on the loading and unloading of goods vehicles; the commuters and other traffic now entering London by road can expect to travel more easily, more speedily and with greater safety to themselves and other road users. As the improvements continue, they will permit a modest increase in the number of commuters by road. If regular bus services, operating at a reasonable speed, can be maintained, they can make a valuable contribution to the movement of commuters, particularly over the shorter distances. The total number of commuters is, however, also increasing and it seems unlikely that the improvement of road facilities will do more than provide adequately for the existing road traffic and for an increase in private car traffic at perhaps a rather lower rate than between 1950 and 1960, leaving much the greater proportion and an increasing volume of commuters to be carried by rail transport (Fig. 2).

Suggestions have been made that the capacity of the road system can be increased by arranging for automatic control of road vehicles or by carrying the road vehicles on moving belts or tracks. Such systems, while capable of development, seem unlikely to have any advantage for urban travel over the development of the railway system, which can more easily be adapted for automatic operation.

Future Development of Railway System

The majority of the great cities are developing or redeveloping urban railway systems. In Paris it is planned to build additional and

deep-level underground railways across the central area. Finance has been made available for the first stage of this scheme, and construction started in July, 1961 (Fig. 3).

In Toronto, an underground railway was opened in 1954 and the development of the system continues. A survey showed that the single line of underground railway so far completed is keeping some 10,000 cars off the street each day. The first sections of underground railway have been opened in Leningrad and Kiev and the Moscow system is to be extended. A new line is to be built in Rome. Extensions to existing metropolitan railway systems are planned or are in the process of construction in Chicago, Tokyo, Osaka (where five new underground railways are planned), Nagoya, Buenos Aires, Hamburg, Berlin, Madrid, Barcelona and Lisbon. New lines are under construction in Milan, Oslo and Rotterdam. Even in Los Angeles, where the local railway system was allowed to close down, plans are now being prepared for some form of metropolitan railway system (Fig. 4).

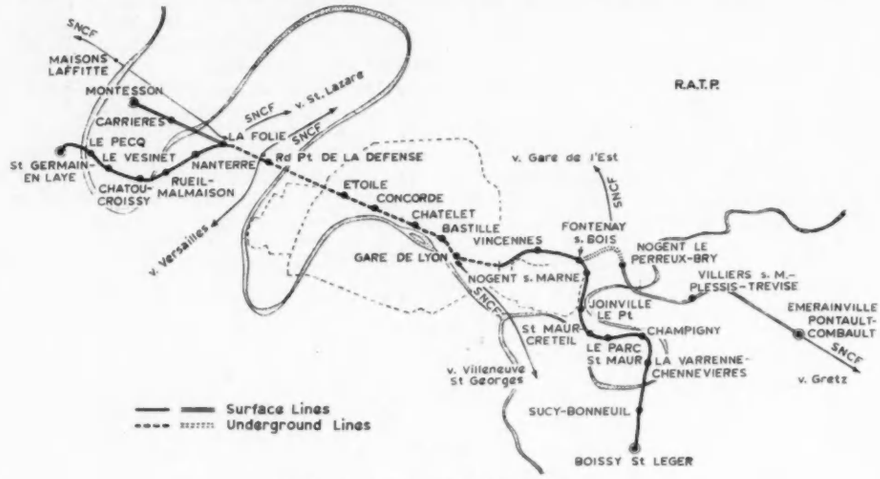


Fig. 3—Paris : Ligne Régionale Est-Ouest

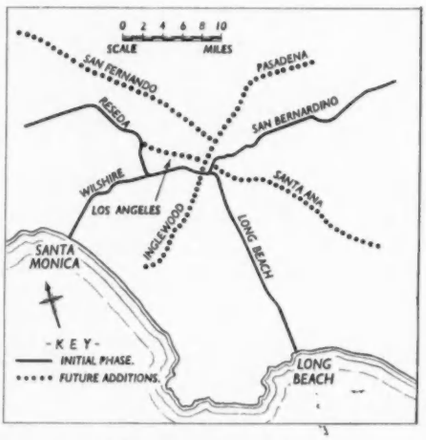


Fig. 4—Plans of Los Angeles railway system

In Washington, San Francisco and in many other large American cities, new or improved metropolitan railway systems are being planned. In some cities (for example, Brussels and Basle) development may take the form of the existing tramway system being run wholly or in part in tunnel under the central areas of the city. A tramcar with one or two trailers operating on segregated tracks is not very different in conception and function from an urban railway.

All these schemes for metropolitan railway development derive from the experience that the needs of city commuter traffic cannot be met by road transport and that the life of the city can be maintained only by developing some form of railway or light railway system, necessarily segregated from road traffic and almost certainly on a different level, in the centre of the city.

Against the background not only of public need but also of world interest and activity in the planning and building of urban railways, the progress in London in the improvement of its urban railways appears to be altogether inadequate.

As in the case of the roads, the existing railways can make a much greater contribution to movement if relief is given at critical points and at critical sections of the system.

Recognised both by transport authorities and by independent committees as of first priority, is the building of the new Victoria tube line, which has been planned to provide new connections and to relieve existing railway routes where serious overcrowding now occurs and relief is most required. The construction of the Victoria line from Victoria *via* Green Park, Oxford Circus, Warren Street, Euston, Kings Cross/St. Pancras, Highbury, Finsbury Park, Seven Sisters and Tottenham Hale to Walthamstow, will fulfil many important functions :

(1) It will provide new direct links across the West End and to and between the main line terminals at Victoria, Euston, St. Pancras and Kings Cross : these terminals are being used by increasing numbers of commuters.

(2) It will provide a new underground line direct from the north-eastern suburbs into the West End, with interchange at in-town stations to all parts of the underground system.

(3) In conjunction with the planned electrification of the Great Northern suburban system, it will provide new rail routes from wide areas north and north-east of London to the West End and to the City.

(4) By providing new and quicker direct facilities and improved station interchanges, it will relieve existing underground routes on sections and at interchange stations which are among those most seriously overloaded during the peak periods. At the most critical points, the overcrowding is such that 150 people are being carried in underground railway cars designed for approximately forty seated passengers and fifty standing passengers.

(5) It will give important relief to road routes, including roads through some of the most congested road junctions in London, such as Oxford Circus.

Among other works for the development of the urban railway system in London which will require consideration, the following are worthy of special mention as giving important relief of congestion and increase of capacity over a wide area :

(1) The removal of the present bottleneck at Borough Market junction near London Bridge on the south-eastern division of British Railways' Southern Region, involving additional tracks and a re-arrangement of the working. This would enable a considerable increase in the capacity of the railway routes into London from south-eastern suburbs and the south-east coast to be achieved.

(2) Victoria line : projection south *via* Vauxhall and Stockwell to Brixton or, possibly, Streatham. This projection would have three important functions :

(*a*) An increase in cross-river facilities, which both by road and rail have little more capacity than thirty years ago, despite the enormous development of commuter traffic and of road vehicle traffic during this period.

(*b*) The provision of major relief to the heavily overcrowded sections of the Northern line between the West End, Waterloo and Stockwell ; to the Bakerloo line between Oxford Circus and Waterloo ; and to the Southern Region and underground interchange facilities at Waterloo.

(*c*) The extension south to Brixton or Streatham would relieve the Southern Region of some local suburban traffic and so increase the accommodation on the Southern Region system available for passengers travelling longer distances.

(3) The extension southwards of the Aldwych line to Waterloo, with interchange with the District line at Temple. This extension would provide a very valuable additional under-river facility and relieve the congestion on existing underground railway and road services over a considerable sector of the West End, at a relatively modest cost, probably within a figure of £5,000,000 at present-day prices.

(4) The relief afforded to the Bakerloo line by (2) and (3) would enable it to be extended south-eastwards from the Elephant and Castle towards Peckham, if traffic considerations warranted this extension.

The private car has for the commuter the advantage that it takes him directly from his home to the office (if he can find anywhere to park at the office). To offset this advantage, car parking facilities must be provided at suburban railway stations. In outer areas, where land can be made available, it may be desirable to build special stations at which cars can be left and a good train service be provided to central London.

When a very large number of cars are parked at a railway station, the distance to be walked from the parked car to the station may in itself be a deterrent to travel by that route. Multi-storey car parks may in part may be the answer to this problem, but there appears to be a case for a commuter's car, perhaps a development of the bubble car, specially designed to carry one person from home to a nearby railway station, in which the commuter can travel protected from the weather and expect to be able to park really close to the suburban railway station. The essential requirement is for the overall journey from home to the office to be as quick and as comfortable as the overall journey by private car.

The new and improved railways must have higher standards of construction and equipment than the existing systems. The new

rolling stock will require greater rates of acceleration and deceleration and higher maximum speeds for use over the longer sections ; cab-signalling and automatic control and driving must be considered ; electric or disc brakes may supersede existing braking methods. The civil engineer, by providing long welded rails and noise absorption materials in tunnels, can contribute greatly to the amenity of rail travel. Without pronouncing on whether or not there is a future for the rubber tyre in the adaptation of railways for modern travel, I believe that by co-operation between civil and mechanical engineers rail travel can be made as quiet and as comfortable as travel by road. There is much matter for urgent study by members of the Institution. Dr. Barwell has indicated in more detail in his inaugural lecture to the Railway Engineering Group some of the problems which require tackling if the expectations of those who believe that railways can continue to be an effective form of transport are to be realised. I hope that the Railway Engineering Group in their deliberations will pay full attention to the special problems of urban railways.

Completion of the modernisation of the existing railway system, coupled with the relatively modest programme of new construction envisaged for London in this lecture, would relieve the existing overcrowded railway services ; they would limit the desire to use private transport for commuting ; and they would provide a modest margin of capacity for an increased number of commuters. Such a programme could be carried out over ten years within a figure of £120 million at present-day prices and it is suggested that it would make at least as great a contribution to the life of London as the corresponding road programme (which is no less necessary). It is worth emphasising in these days of strict control over capital expenditure that the cost of railway improvements includes that of the rolling stock to run on the railway and of signalling, but the cost of road vehicles and of policing is not included in the estimates of cost of road improvements. Beyond the programme of railway improvements outlined in this paper, there is likely to be a continuing need for improvements which cannot be specified in detail at this stage. Without a programme of this character, life in London will become progressively more difficult and the proper functioning of the city will be progressively impaired.

Staggering of Hours

The encouragement of the staggering of hours of office and industrial workers and of school children has for a long time been advocated as a means of relieving overcrowding in peak periods and of increasing the carrying capacity of the road and rail systems. What has been achieved in this way is often under-estimated.

Since 1957, when the campaign for the staggering of hours of work in central London offices was intensified, approximately 50,000 people have had their hours of starting and finishing work changed. In consequence, the number of people finishing work in the peak quarter-hour period of the day (5.30 to 5.45 p.m.) has been reduced by nearly 20,000. This is an achievement of considerable magnitude. By comparison, the carrying capacity of a tube railway line in a quarter-hour is 8000 in each direction. Or again, 20,000 people travelling by private car, assuming the present average load of 1½ persons per car, would take up road capacity equivalent to twenty-seven traffic lanes, assuming 2000 cars per hour per lane.

Further relief is practicable in this way. It will assist in reducing overcrowding, but it cannot be expected in present circumstances that staggering of hours can be carried to the point where all commuters can travel in comfort by the means of transport of their choice.

Overhead Rail Systems

There seems no future for the construction of overhead monorail or suspended railways in cities which are already fully built up. The destruction of property and amenity would be too great. The problems of interchange with existing underground railway lines and other transport facilities would be almost insuperable.

The Further Future

In the further future there is the possibility that such devices as the fuel cell can be developed as a main power unit or that the linear induction motor may provide a better solution to the problem of acceleration on an urban railway system than the present conventional traction system. The principle of the air cushion embodied in the hovercraft may be capable of adaptation for use on railway systems. The gyroscope or flywheel may have a part to play in the propulsion of urban transport vehicles. Here is a further range of longer-term problems which may be worthy of attention by mechanical engineers.

Conclusions

It is suggested in this lecture that the problems of commuter traffic in conurbations should be tackled and can be solved on these lines. First, the nature and extent of the present movement must be defined and measured. Secondly, the planning and location of housing, industry and commerce, must proceed in parallel with the planning of transport facilities. Thirdly, the road system must be improved to the maximum extent that can be done without incurring unreasonably high cost or destroying the amenities and life of the city. In the planning of the improvements to the road system and in the use of the road system, traffic engineering techniques must be employed to the fullest extent. Fourthly, if a very large city is to continue to live, an urban railway system must be maintained and developed to provide for the majority of commuters to travel quickly, comfortably and cheaply. The property and land for these road and rail improvements need to be earmarked now, in default of which developments may make the schemes prohibitively costly or even impracticable.

It would not be appropriate in this lecture to make suggestions or offer views as to how these projects are to be financed, but there are grounds for believing that, if approval could be given to the development of the urban railway system on approximately the same scale and at the same rate as that of the road improvements envisaged in the Nugent Report, the problem of financing improvements on this scale would not be insurmountable. Without them, commuters in London and elsewhere will continue to journey in increasing discomfort and inconvenience and the function of London and other great cities will be frustrated.

Multi-Storey Car Parks

The Traffic Engineering Group of the Institution of Civil Engineers met on December 14 to discuss a paper on "Multi-Storey Car Parking Garages," by L. T. C. Beasley, M.B.E., B.Sc., A.M.I.C.E., Chief Engineer's Department, London County Council. Mr. R. W. Mountain was in the chair.

INTRODUCING his paper, Mr. Beasley remarked that car parks should form an integral part of a town or city's highway design, and not be treated as incidental to building development. Speaking for himself, not necessarily for his department in this or any other matter, he believed that parks should be sited primarily to avoid disrupting the flow and circulation of traffic. To this end he suggested that the ideal would be a park, for perhaps 600 or 700 cars, erected directly over a suitable highway ; through traffic would continue to enjoy a clear run, under the building ; for traffic to and from the park the highway would be widened, as it approached the site, to the extent necessary to provide it with deceleration (and acceleration) lanes that would finally rise to serve as access ramps for the park.

From among a wide selection of slides of multi-storey parks Mr. Beasley was able to instance, as a near-example of his suggested design, only the five-floored Autorimessa at the end of the motor road leading into Venice. A speaker was quick to point out that this was no very near-example, for the motorist had virtually no option but to leave his car in the autorimessa and go on by gondola or vaporetto ; in siting a park, the main consideration, according to this speaker and many others, was that the motorist always wished to end up very near indeed to his precise destination : the customers' convenience must therefore be the primary factor. That view prevailed ; though the importance of Mr. Beasley's factor, in so far as the aim was to minimise the inevitable interference with street traffic while parks are filling or emptying, was stressed by many speakers, notably by one who advocated mechanical or automatic parking garages in preference to the ramped type.

The chief advantage claimed for mechanical parks arose from the axiom, strongly endorsed by a police representative, that a large number of small parks would always be preferable to a small number of large parks. The minimum worthwhile capacity for a ramped park was stated to be 300, compared with twenty-five for the mechanical type ; an American seventeen-storeyed park that housed sixty-eight cars, on a site 25ft by 67ft, was instanced ; such parks could readily be incorporated in office buildings, possibly for the use of the tenants only. The normal rate of discharge from a mechanical park was stated to be one car per minute per unit, compared with one car every ten seconds from a typical ramped park ; this latter flow (360 v.p.h.) could overtax the capacity of one lane of the get-away street, claimed the advocate of mechanisation. But the Group failed to warm to the subject of ramped versus mechanical ; presumably each type was seen to have its place.

A large proportion of the evening was spent on the engineering aspects of multi-storey parks of the ramped type. In addition

to slides, there were films of the construction of the recently completed parks at Bristol and Leicester ; and much of the discussion was devoted to the achievement of efficiency in the use of space, and of economy in capital cost. The efficiency of a car park was accepted as being the area of the car spaces (16ft by 8ft per car) expressed as a percentage of the total floor area. The meeting was told of efficiencies ranging from 40 to 80 per cent ; using right-angle parking (the angle most economical of space) one speaker had found 61½ per cent to be the maximum attainable, though this could be increased to 76 per cent by double-banking.

Costs per car space showed a wider spread. Excluding the cost of land, one speaker claimed £220 per space as a common achievement, with £135 as his record low ; a car factory's storage park for 3300 cars had cost £165 per space. Later speakers implied that these figures could be achieved only under ideal conditions : city sites were seldom ideal ; one was instanced, requiring piled foundations for a six-storey park, costing £534 per space. The consensus of opinion was that the constructional cost could seldom be less than £300 per space, and that, allowing for land purchase, the capital outlay on a multi-storey park in a city would normally be of the order of £1500 per space. It was pointed out that there could be no saving in going underground : the avoidance of land costs was offset by higher constructional costs, particularly in respect of the fire risk ; the Marble Arch park (under Hyde Park) would cost about £1000 per car space, and the estimated cost for a possible two-storey park under the Horse Guards Parade worked out at £2000 per space.

One contributor, speaking from experience of the business side of multi-storey parking in another country, set little store by the engineers' ingenuity in cramming the maximum number of car spaces into the building, or in reducing the cost per car space to a minimum ; he would rather rent and operate a park capitalised at £1000 per space than one for which the figure was £500! That was presuming the money had gone into the acquisition of the right site, and into satisfying the convenience of the customers in other respects also, particularly in facility of acceptance and discharge, and in ease of moving into and out of the car space—attendant-parking being wholly uneconomical. Clearly, in his eyes, what mattered was that parkers should find the building a pleasure to use, and the true measure of the efficiency of a park was the extent of its patronage.

On the subject of financial viability the same contributor suggested that if a park could not stand on its own feet it must be wrong in place or time, though he agreed with home speakers that street parking meters were an essential feature of the places around the park ; some misgivings were expressed over Leicester's decision to drop its metering scheme. Among many examples of the effect of parking meters, the London Wall park was mentioned as one initially unpatronised that has now reached capacity use owing to the spread of parking meters ; its charges are 1s. an hour, 7s. a day, £2 a week : receipts cover the operating expenses only ; the constructional cost of this under-road park, 410 yards long, with five access ramps, had amounted to £1300 per car space. The City of London was held up to the Group as a model local authority in having a long-standing policy : in 1956 they decided that there should be off-street parking for the city's 6000–7000 all-day parkers ; twelve sites for parks of capacity 500–600 were designated ; private enterprise has been responsible for three of five already completed or in hand, the corporation for the other two (without trading facilities) ; the target remains unchanged, and this progress towards it was reckoned commendable.

To subsidise or not to subsidise? The question was not discussed at any length. The speaker from overseas conceded that a municipality was entitled to its own policy in the matter ; he only required that, in any town, if one park were subsidised then all should be. In Britain, off-street parking is tending to be viewed as an amenity, as one speaker described it ; there was no support for a lone view that anyone who could afford to drive could afford to park.

In the Group's original programme of meetings the subject for this one was shown as the traffic design of parking garages. In the event, turning circles, aisle widths, ramp gradients, and other details of traffic design provided little material for discussion. The only hint of dispute arose over a suggestion made in the paper, that ramps could be made to seem less steep by camouflaging the side walls with strips at the same gradient as the carriageway, or steeper ; so to delude the driver struck one member as very wrong. Finally, the Group's vocabulary was extended by a sobriquet for the slot machine properly known as a time-dated ticket dispenser : ticket-spitter.

Maintenance Experience of the Calder Reactors

At a meeting of the Institution of Mechanical Engineers held in Bristol on December 14 Mr. J. R. Treharne, A.M.I.Mech.E. presented a paper based on twelve years of operating experience at the Calder Hall nuclear power station. He discussed the problems of maintenance and of the organisation of work programmes and reactor test schedules, co-ordinated with refuelling operations. Extracts from the paper are reproduced below.*

CALDER HALL nuclear power station consists of two stations, Calder " A " and Calder " B," each having two reactor units of the natural uranium, carbon-dioxide cooled, graphite-moderated type. Each reactor supplies steam to two 23MW turbo-alternators, the plant operating on a dual pressure cycle, each turbine being supplied with high- and low-pressure steam at nominal pressures of 200 lb per square inch gauge and 50 lb per square inch gauge.

Power from the first reactor at Calder Hall nuclear power station was switched into the national grid transmission system by Her Majesty the Queen on October 17, 1956. The last of the four reactors and associated generating equipment went into service on April 29, 1959. Since the commissioning of the first reactor approximately fourteen years of reactor operating experience has been accumulated. During the period the output of each has been increased from 180MW (Th) to over 210MW (Th) and the output from each turbo-alternator from 21MW (E) to 23MW (E). The reactors now produce more steam than can be used by the turbines and the electrical output of the station will be increased further when the turbines are rebladed.

Since the early days of the station the plant utilisation factor has been high and at the present time this is better than 83 per cent†. This has been achieved although the reactors have to be shut down and depressurized for recharging with fuel, produce plutonium and electricity, and are used extensively for experimental purposes. High plant availability has been attained by maintaining and modifying the productive units during reactor recharging operations and by prompt rectification of faults when they have developed.

Design changes made too late for incorporation during the construction of the earlier reactors and alterations found to be necessary as the result of operating experience have necessitated substantial plant modifications and additions on operating reactors. The installed plant at Calder Hall in terms of items, i.e. valves, motors, etc., is between two and three times that found in conventional power stations operating eight turbo-alternator units.

Improvements in the fuel-handling equipment and operating methods have produced a gradual reduction in the time required to recharge reactors—from ten weeks to approximately three weeks. This is rather shorter than the time required to complete engineering work in present circumstances.

A detailed description of the plant is given in the Journal of the British Nuclear Energy Conference of April, 1957‡.

Inspection Code of Practice

Before the Calder plant was commissioned it was made clear that not only would it be operated and inspected in strict compliance with the Factory Acts but should comply wherever possible with the spirit of the Acts. Several factors had to be taken into consideration. For instance, access to the interior or exterior of a reactor pressure vessel is not possible once the plant has been commissioned. The main gas circuit at Calder had been designed on the assumption that entry would not be possible throughout the working life of the plant and only manholes for constructional purposes had been provided. Further, whilst properly construed as steam generating equipment within the meaning of the Act the heat exchangers at Calder are not furnace heated.

A committee was formed to consider the inspection aspects of the plant and to formulate a code of practice. The main recommendations of the committee were :

(*a*) Samples of the material used in the construction of the pressure vessel should be irradiated in the reactors, and at specified periods throughout the life of the plant samples should be withdrawn for examination and testing.

(*b*) The movement of the vessel branches should be monitored to give early warning of creep should this occur.

* Works engineer, U.K. Atomic Energy Authority, Calder Works.

† $\frac{\text{MW days (E) generated throughout the year}}{\text{Number of turbo-alternators} \times \text{MW rating} \times 365}$

‡ 1957 *J. Brit. Nucl. Energy Conf.*, vol. 2, No. 2, p. 43, Symposium on Calder Works Nuclear Power Plant, November 22 and 23, 1956.

(*c*) The heat exchangers should be surveyed internally at two-year intervals.

(*d*) The bellows unit convolutions and ducting should be surveyed internally at five-year intervals.

(*e*) Steam circuits should be surveyed at two-year intervals.

(*f*) The gas circulator impellers should be inspected at intervals of two to three years.

When the feasibility of internally surveying the heat-exchanger shells and ducting of operational reactors had been established, design changes were introduced which increased the number of manholes and provided the bellows units with removable internal fairings. Because of the advanced state of construction at Calder, not one heat-exchanger gas circuit had all the modifications incorporated at the time of commissioning.

Subsequently, a permanent committee was formed to review periodically the Inspection Code of Practice and to consider the reports on the surveys and vessel movements and the results of tests on irradiated steel samples, etc. This committee, meeting at intervals, actively directs the measures to be taken to ensure the continued safety of the reactor pressure circuits.

The measures taken to ensure the integrity of the reactor gas circuits and to maintain gas leakage within acceptable limits is an important feature of reactor maintenance.

Reactor Pressure Vessel

No deterioration or change in the condition of any reactor pressure vessel has been detected since the plant was commissioned. At intervals irradiated steel samples have been withdrawn from the vessels ; no significant change in the properties of the material has been found other than a small but expected rise in the brittle fracture transition temperature. Radial, tangential and vertical readings of the position of the vessel branches and ducts taken with reference to the biological shields have remained unchanged.

Heat Exchangers

Entry into a heat-exchanger shell is only allowed when the whole of the reactor gas circuit is depressurised, but as the reactor vessel must always contain carbon dioxide at just above atmospheric pressure the gas circuit concerned must be safely isolated. The circuit isolating valves are closed and locked and all pipe lines through which carbon dioxide might leak are disconnected. In the top duct, a balloon is inserted and inflated in the heat-exchanger elbow between the cascade section and the manhole, the gas circuit relief valves removed and the space between the balloon and the isolating valve is vented by blowing in air. At the bottom of the circuit the blower top casing is removed or a blank disc is fitted between the blower outlet and the first bellows unit.

Entry into a heat-exchanger shell is made through a manhole in the top duct elbow via a temporary change-room. Before the shell can be examined internally fifty-four internal doors have to be removed and each compartment radiologically surveyed and tested for carbon dioxide.

Radiation levels in all parts of the circuits have been well within the permitted tolerance for continuous occupation. Radioactive contamination levels in the circuits have not been high and no significant increase has been detected since the first inspection of No. 1 circuit, reactor 1, in February, 1957. Typical levels on the surface of the shell, tubes, ducts, etc. at the top of a heat exchanger are :

	Top of heat exchanger	Bottom of heat exchanger
Surface contamination counts per second by probe, $\beta\gamma$ ...	1000	500
by swab, $\beta\gamma$...	500	200
Air samples, disintegration/m³ of air per minute	1000	—

At the time of writing twenty-seven heat-exchanger shells have been entered and no sign of significant deterioration has been detected. Minor cracks in non-load-bearing welds of the vertical support plates have been discovered and as a precautionary measure the affected weld material has been removed to avoid risk of crack propagation. In one instance a slight bulge was found on a bottom dome and was proved to be a surface lamination by grinding away metal until all trace of the defect had been removed. The interior surfaces of the shells appear to be in the same condition now as when they were commissioned as they have retained the dark appearance left after treatment with colloidal graphite, with no signs of scale or corrosion. The tube elements have a clean bright surface with texture as left by shot blasting, but the colour has changed to grey-black or copper coloured speckle dependent upon the position in the shell. Tube distortion has not been detected but slight bowing of some of the tube support plates was noted after the first commissioning run on most of the heat exchangers. Further movement has not been detected in service. Tube bank spacing clips, used for construction purposes only and which could not be removed after erection, had in some cases broken free and showed signs of chattering on the tubes.

Painting of the exposed structure of the heat exchangers presents a problem. When a reactor is in service the level of radiation imposes a severe restriction on working time and in the region of the top ducts this is only about an hour in each working day. During a recharge insufficient time is available to complete painting and an extended shut-down for this purpose cannot be contemplated. Painters work on the structure for the maximum time permitted with a reactor in service and then have to be found work in non-active areas.

Ducting

As the main gas circuits were not provided with means of access for routine internal surveys in service, sections of the gas ducting have to be removed to gain access for the initial surveys. Design modifications are then incorporated which enable future surveys to be completed without dismantling the circuits.

Personnel entering ducting wear full protective equipment and if double isolation is not provided " air line " masks are also worn. Radioactive contamination and radiation levels are comparable with the levels found inside the heat-exchanger shells. Near the main isolating valves the ambient temperature is rather high, the value depending on the time a reactor has been shut down.

The first elbows to be modified were returned to the manufacturer's works for manholes to be fitted and for the purpose were completely decontaminated and allowed to leave the site without restriction. The time taken to attain the required decontamination levels around the cascade sections was unacceptable if loss of reactor production was to be avoided during subsequent reactor shut-downs. Provided manholes are fitted under surveillance of works staff complete decontamination is not necessary, as contact with the cascades section can be prevented by covers bolted to both sides. All elbows are now modified on site by contractors whose staff are non-radiation workers, and who can, when required, be used to cut seal welds on the heat-exchanger circuits and manhandle the contaminated duct sections which have the open ends sealed to prevent the spread of contamination.

No deterioration or defects have been detected during survey of ducting and bellows units but a number of bellows convolutions have apparently closed when compared with other convolutions in the same unit. These deformations are believed to have occurred during manufacture, as no logical explanation has been put forward to account for the change being caused by operating conditions.

Main Circuit Isolating Valves

Early in the life of the plant a main circuit isolating valve spindle failure occurred. The spindle was made of high-tensile brass which was found to be unsuitable for high-temperature operation, and replacement stainless steel spindles have now been fitted throughout all reactors. To avoid the complication which would have arisen owing to the ingress of air had the valve plugs been removed, in each case the spindle was replaced without moving the plug from the closed position, although as designed, plug and spindle were fitted as a complete assembly. After removal of the valve bonnet the old spindle was released by cutting away sufficient metal from the side of the spindle nut to give escape from the T-slot in the plug.

To gain access to the four reactor inlet valves on reactors 1 and 2 reinforced concrete shielding 4ft thick had to be cut away. On the later reactors the shielding is constructed of precast slabs which can easily be removed.

Radioactive contamination levels were low, but P.V.C. coveralls, gloves, rubber boots and dust masks were worn by personnel entering the valve body.

Gas Circulators

The gas circulators are surveyed mainly for the purpose of examining the condition of the impellers which are of forged sections riveted together ; this requires the top casing of each gas circulator to be lifted. It was initially specified that survey should be at intervals of not exceeding three years, subject to initial survey of selected machines after one year's service. The survey period has been relaxed and can now be extended to five years after the initial survey, provided impeller concentricity is checked yearly at the inlet eye and remains unchanged. It has been found that the silicon rubber standstill seal deteriorates and disintegrates after about three years in service. As the circulator top casing has to be lifted to replace this seal, each circulator may have to be opened up at intervals of two years to three years throughout the life of the plant unless a more durable material can be found.

Since the first circulator was opened in February 1957 no significant increase in radioactivity levels has been detected. The main hazard arises from contaminated patches on the impeller and the interior of the circulator casing, typical levels being 150 counts per second beta gamma by probe and 50 counts per second beta gamma by swab. The contamination usually adheres firmly to the surface, presenting no hazard to persons working in the vicinity, and no attempt is made to remove this contamination other than by wiping with a solvent-impregnated cloth should this be considered necessary.

So far twenty-two gas circulators have been surveyed and on only one occasion has

a defect in an impeller been detected. This was attributed to a bent shaft (presumably damaged during construction), which caused heavy rubbing of the impeller inlet labyrinth seal, resulting in general distortion and loosening of rivets. On the first circulators to be commissioned gas fairings attached to the core-hole covers broke free in service. In a number of instances the rubber standstill seal was damaged or torn away.

Carbon Dioxide Leakage

Loss of carbon dioxide through leakage from a reactor circuit is of concern both because of the cost of the gas lost and a health hazard which may be presented. During construction of the reactors considerable time was devoted to producing a circuit as leak-tight as possible but in service the cost of production lost in reducing leakage must be carefully balanced against the cost of gas which can be saved, provided no health hazard is involved.

At Calder reactor economics and health consideration are such that outage time cannot be justified solely to reduce gas losses which are not in excess of the order of a ton per day per reactor, with higher leak rates being accepted for short periods of time. Provided great care is taken in remaking all the various joints and seals in the circuits, gas leakage can be kept within acceptable limits without the need for elaborate testing procedures. Therefore, on operating reactors after maintenance and circuit modifications, leak testing is at working pressure and ambient temperature only. Individual heat-exchanger circuits (which include the gas circulators) can be tested by pressurising between the circuit isolating valves, permitting fuel-recharging operations to continue without interference during leak testing. The testing of the isolating valves themselves presents special problems which are considered later.

Sources of carbon dioxide leakage can be divided into two groups :

(*a*) Running components, i.e. rotating and reciprocating shaft seals, valve glands, leakage past valves, etc., where in most cases leaks can be detected and often rectified during normal reactor operation.

(*b*) Joints of all kinds, cast steel pressure casings, etc., covered by lagging which can only be tested and leaks rectified when a reactor is shut down. Limited testing only is possible on parts of the circuit outside the biological shield.

Leakage from all rotating and reciprocating seals (except the gas circulator shaft running seal) and past stop and safety valves, etc. can be quantitatively evaluated at any time. Leakage from valve spindles is checked by the application of soap solution but the valves in the reactor valve chambers can only be tested when the reactor is shut down or at low power. Measured losses are low and normally are kept without difficulty below a few hundred pounds of gas per day per reactor. Leakage from valve spindles, etc. is also thought to be insignificant but occasionally bad leaks can be overlooked owing to the difficulty in testing, i.e. noise, confined space, heat, etc. It is standard practice to check all these potential sources for leakage immediately after a reactor is returned to service after a major shut-down. Rectification of the leaks detected invariably reduces initial high losses to an acceptable level.

The driving shaft carbon gas seals of the fifty-four-way selector valves, the precipitator wire drive shafts and the carbon piston rings and piston rod seals of the sampling plant compressors have been trouble free, and have a useful life in excess of two years provided the moisture content of the gas in the reactor circuit is kept above an estimated value of about ten parts per million. There are indications that lower concentrations of moisture result in rapid wear of components. The seals of the fifty-four-way selector valves are examined annually and replaced if necessary as a precautionary measure, as failure in service results in loss of channel sampling over a section of the reactor until the defect is rectified.

The impeller shaft running seals have been remarkably trouble free ; under normal conditions tests have shown that gas losses are negligible. On two occasions the floating stationary portion of a seal jammed owing to wear of guides and spring components, allowing some escape of gas.

Gas circulators are responsible for a large proportion of the gas loss which occurs from items in (*b*). The O-rings which seal the diffuser nuts " set " after a period of service at high temperature and lose their ability to form a gas-tight seal. Temperature cycling results in leakage from the casing joints and other parts no matter how carefully the circulators are reassembled and tested after maintenance. Therefore there is no incentive to produce perfectly gas-tight circulators when such action involves loss of production, and after overhaul they are only leak tested at ambient temperature and normal working pressure by the application of soap solution ; any reasonable leakage which develops when a circulator is brought up to operating temperature is accepted.

Leakage which occurs from the main circuit isolating valves is mainly attributable to difficulties in making satisfactory joints as the valves are located in confined spaces and pressurising for testing presents problems. As these valves are fitted between the heat exchangers and pressure vessel, bonnet joints cannot be leak tested at the normal operating pressure unless the reactor vessel is pressurised. Such action would cause serious loss of production, as fuel recharging would have to be stopped while the reactor pressure vessel was sealed and the test completed. The loss of production would be further increased if testing was to be at near-operating temperature. Therefore a bonnet joint is tested by pressurising the bonnet space with carbon dioxide to the maximum pressure obtainable, about 30 lb per square inch owing to leakage past the valve faces. The subsequent losses which may occur in service are accepted.

Testing of the circuit joints, etc. normally covered by lagging, after the completion of a recharge is not acceptable as, in addition to the time required to conduct such tests, further outage time would be required in order to replace lagging and to rectify any defects.

Carbon Dioxide Leakage from the Reactor Pressure Vessel

A leak in a pressure vessel may have serious implications, therefore any sudden increase in gas loss from a reactor which cannot be explained must be shown to be outside the main biological shield. This can be confirmed if it can be shown that carbon dioxide is not present inside the shield. However, a carbon dioxide determination in the coolant air leaving the shield is not a rigorous check, owing to the presence of carbon dioxide picked up by the air before entry. This difficulty is overcome by determining the total volume of carbon dioxide in the air drawn into the shield and the total volume of carbon dioxide in the air passing into the discharge stacks. If a satisfactory balance is obtained no serious leakage can be present.

To make this assessment the concentration of carbon dioxide and the total inflow and outflow of air at every point of the thermal shield cooling system must be measured and assessed ; this requires sampling pipes to be fitted at every air intake point. The balance sheet produced can also indicate the approximate sources of carbon dioxide leaks external to the biological shield by showing areas of high carbon dioxide concentrations. Tests by injecting known quantities of carbon dioxide at various points have indicated that leakage of less than $\frac{1}{4}$ ton of carbon dioxide per day inside the biological shield can be detected.

Tests carried out on all reactors at various times have revealed no detectable increase in the carbon dioxide concentration of air inside the biological shields.

Heat-Exchanger Steam Circuits

Steam circuit maintenance follows conventional practice and whilst presenting no new technical problems these circuits account for a large proportion of the total work load associated with the heat exchanger, as thirty-two separate self-contained steam-raising circuits are involved.

One heat-exchanger tube failure in a bend external to the heat-exchanger shell (a pin hole with tube thinning) has occurred in the high-pressure section of No. 8 circuit, reactor 4. Extensive tests, including metallurgical examination of bends cut from a representative tube element in an earlier reactor, revealed no deterioration in the tube examined and no satisfactory explanation for this one failure has been forthcoming.

Gas-Circulator Drives

The electrical drives of the gas circulators have not been entirely trouble free as occasional brushgear flashovers have caused machines to trip and shut down reactors. High machine rating, continuous operation at full power and partial recirculation of cooling air within the machines are believed to be contributory factors in the cause of the trouble. Measures which have included minor design changes, stringent routine maintenance at programmed intervals and complete overhaul to bring the machine to the " as new " condition during reactor recharge periods, have ensured that reactor trips are infrequent occurrences and have kept within acceptable limits loss of production attributable to the machines.

Mechanical reliability has been excellent and defects have only been detected during routine maintenance. The most important of these was a defective Hirth coupling, a bent shaft causing damage to an impeller, and defective keys in the pony motor drives.

Control Rod Actuating Mechanisms

Before control rod actuating mechanisms are reinstated in a reactor they are visually inspected for signs of corrosion or defect. Frictional resistance is also measured with a torque-meter and the drop test characteristics are determined in a test facility which produces a trace of control rod insertion velocity against time. As a mechanism might be damaged or incorrectly fitted when being installed in a reactor, the control rod insertion time is rechecked in the reactor by fully withdrawing the rod and timing with a stopwatch the duration of free fall as shown on the control-room control rod position indicator.

The actuating mechanisms have given reliable and trouble-free service and no control rod has ever failed to drop into a reactor when tripped under operating

conditions. On two occasions early in the life of the station single control rods, which had been held out for long intervals of time during a reactor shut-down, failed to drop when tested. The first failure was found to be due to moisture which had entered the shut-down reactor, collected in the upper parts of the charge tubes and then condensed in the mechanism causing corrosion of bearings. The second failure was due to a retaining bolt working loose and allowing the eddy current brake disc to rub on the magnet assembly. In both cases insertion of the rods could be effected by motoring the rods under power by means of the sine potentiometer. Subsequent tests on actuating mechanisms showed that provided bearing races are a slack fit on the shafts, even with locked bearings, control rods will drop under gravity, usually at a substantially reduced speed. After the first incident steps were taken to control moisture entering the reactor during shut-down periods by purging as necessary with carbon dioxide and maintaining a positive gas pressure of 2in water gauge in the pressure vessel. Since then no further trouble due to moisture has occurred. When reactors are in service the mechanisms are working in an atmosphere of dry carbon dioxide and corrosion does not occur, but for a number of reasons lubrication by normal high-temperature grease would be preferable to the molybdenum disulphide dry lubricant now in use. The feasibility of using such a grease is being investigated.

Each actuating mechanism is completely dismantled for examination at prescribed intervals, when bearings are replaced irrespective of their condition. Over a period of time minor changes in design have occurred and overhauled mechanisms are rebuilt to the latest specification.

Charge and Discharge Equipment

As radioactive materials are handled the charge and discharge equipment is rather complex and was designed and built without the benefit of previous experience in this particular field of fuel-element handling. Machine failures were initially a major cause of delay in refuelling but modifications carried out over a period of time have improved performance to a marked extent and the equipment is now giving good and reliable service. The essential modifications were concerned with improving the reliability of the cartridge deflecting equipment, the slack grab cable and overtension devices and the charge chute drives, and in providing fuel element viewing and other facilities.

At the present time failures are mainly confined to the electrically operated grabs which work under difficult conditions, and with the grab cables which have electrical conductors wound round the central steel load-carrying cable.

The closed circuit television equipment used for viewing inside the fuel-element channels of a shut-down reactor was initially provided as a viewing facility only. A need soon arose for a grabbing facility to remove loose components whilst in the field of view of the camera and devices for attachment to the camera head were improvised and fitted. Over a period of time improved grabbing equipment was developed and cameras now in service have specially designed remotely operated grabbing devices. There is some difficulty in providing sufficient cold gas for camera cooling, as the cooling gas is heated as it passes through the reactor in a tube about 40ft long in ambient temperature often exceeding 140 deg. Cent. This restricts the time a camera can be kept in a reactor without unacceptable deterioration of picture quality or risk of damage. The cameras are knocked when passing up and down the charge chute and when grabbing loose components, and substantial maintenance is required to keep the equipment continually in service.

The fuel-handling equipment at Calder does not become radioactive as the reactors are shut down for refuelling, but parts become radioactively contaminated. Provided no complications exist, such as the presence of irradiated fuel stuck in a machine, protective clothing gives complete protection during maintenance ; in most cases P.V.C. gloves provide adequate protection.

Turbine Hall Plant

The turbines have given little trouble and despite the steam conditions (approximately 10 per cent wetness) blade erosion is not excessive. Some of the turbines are now being rebladed to use the excess steam produced owing to the higher thermal power output of the reactors. The steam dumping equipment initially was troublesome owing to tube leakage. Each atmospheric condenser absorbs the full output of desuperheated steam from a reactor and until baffles were fitted the inflow of steam violently agitated the condensate which caused loosening and fracture of tubes owing to induced vibration.

Planning and Control Work During Reactor Recharges

Loss of production due to maintenance is at a minimum if all essential engineering work involving productive plant not provided with standby units is completed in the time taken to recharge a reactor, and this ideal must be approached as closely as possible.

The work load during a recharge must be reduced to a minimum and all plant which can be taken out of service without loss of production must be maintained outside the recharge period. It has been found possible to release most of the reactor ancillary plant, including switchgear, transformers, lubricating and sealing oil pumps, cooling water pumps, air and carbon dioxide receivers, etc. The main reactor gas circuit can only be maintained or modified when a reactor is completely shut down and depressurised, but steam circuits, gas-circulator drives and electrical generating equipment, can be maintained when a reactor is on load provided a reduction in output and loss of production are accepted.

The time taken to recharge a reactor can vary for a number of reasons but for straightforward recharging this is now about three weeks. With the staff available all engineering work at present required on essential productive plant cannot be completed in this time. When it is seen that the time required to complete essential work is longer than the time scheduled for a recharge, loss of production is minimised by returning reactors to service on a reduced number of circuits, usually within a day or so of the completion of a recharge. This requires the maintenance programme to be built around the requirements of the reactor gas circuit. This can mean that heat-exchanger circuits are taken out of service for attention to the gas circuit, are returned to service to enable other circuits to be released and, when the reactor is back on load, are taken out of service again for work on the steam circuits and gas circulators. This method increases the work load but significant reductions in loss of production are achieved.

The time taken to complete reactor maintenance can be substantially reduced should this be required, but staff would have to be increased proportionally.

Proving Tests Before a Reactor is Returned to Service

Reactor safety depends upon the integrity of the reactor safety circuit lines, electrical trip relays and the associated reactor protective instruments. During a major reactor recharge this complicated installation may be taken apart, serviced and perhaps modified by independent specialist engineering sections, and before a reactor is recommissioned it is essential that the whole installation should be thoroughly tested and proved as an integrated safety system.

The principle of the tests carried out is that each separate tripping circuit which operates when the safety circuit lines open should be tested with the reactor in the normal operating condition, i.e. gas circulators running on main motors and control rods withdrawn a few cycles. The safety circuit lines are then opened deliberately by operating, for example, a heat exchanger out-of-balance coolant flow trip. When this is done the control rods should automatically be inserted, the main electrical drives of the gas circulator should be de-energised and the pony motor drives should take over and maintain coolant gas flow. Test schedules covering every possible trip sequence are used.

These proving tests are carried out after all vital engineering work has been completed, and immediately prior to a reactor returning to service. An abridged schedule is used after a minor or short shut-down when no work has been done on the reactor safety circuits. Every test listed in the schedule is witnessed by senior members of the engineering and operating departments and when all tests have been satisfactorily completed these people append their signatures. This document forms part of a " start-up " certificate which includes a statement submitted by the engineering department certifying that all plant which has been subject to maintenance is in good order and is ready for service, instruments are correctly calibrated, etc.

Conclusions

Calder experience extending over fourteen years of reactor operating has shown that under proper surveillance, major engineering modifications and the survey and maintenance of the plant can be undertaken in safety by essentially standard engineering techniques and with plant availability factors comparable with those attained on conventional plants. Hazards from nuclear radiations, whilst different, are no greater than the hazards which exist on many conventional industrial plants and no difficulty has been found in keeping individual exposure levels well below the permitted maximum of five rem per year.

Present evidence indicates that heat-exchanger circuits can be surveyed internally as a matter of routine throughout the life of the plant and that the present standard of plant reliability and availability can be maintained.

Recruitment and training of engineers and craftsmen has presented no great difficulty, for if persons with an appropriate background are selected the new techniques are quickly learnt and working conditions soon become familiar.

Considering the novel nature of the plant and the many unknown factors at the time of construction the teething troubles and modifications and alterations found to be necessary have been remarkably small and are a tribute to the designers and manufacturers concerned and emphasise the basic soundness of the plant and the care taken over the design.

Plunge Grinding Machines of Unit Construction

BASED upon an extensive experience in designing and manufacturing cylindrical grinding machines for the automobile industry the Newall Engineering Company Ltd., Peterborough, has introduced an interesting new series of plunge grinding machines. For the construction of this " MU " series of machines there has been developed a comprehensive range of standard units which can be selected and assembled to provide a special purpose machine with a fully automatic working cycle and, if required, with automatic work loading and transfer equipment. The machines are available with work length capacities of 18in, 24in or 30in ; they swing up to 12in and grind a maximum diameter of 7in with a 4in wide wheel.

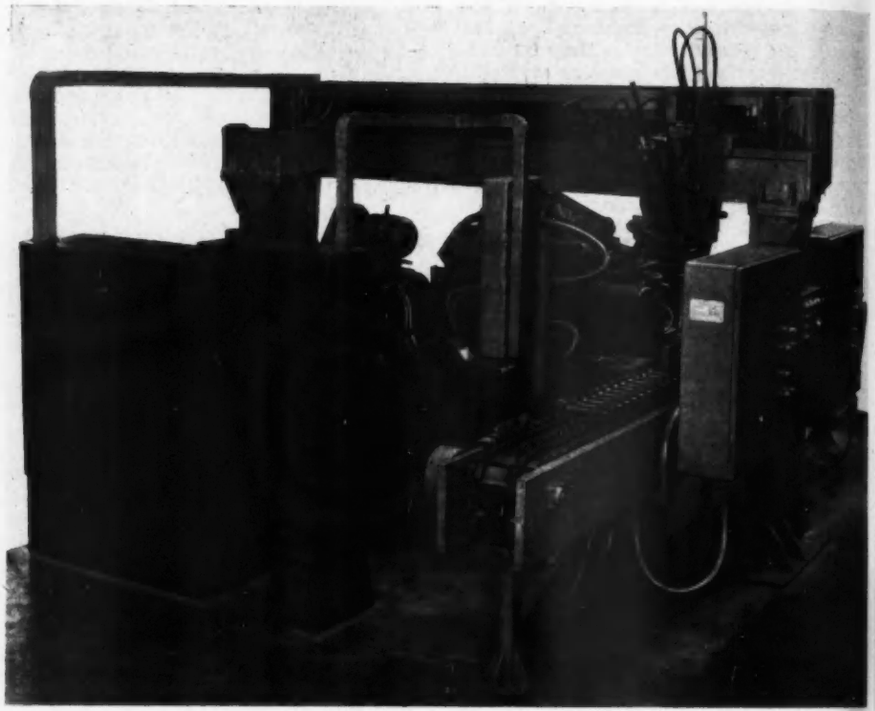
The principle of construction with standard units has been adopted to provide at an economic cost a compact special purpose machine requiring the minimum floor space, and which gives a high rate of production to consistent close limits with little or no operator supervision. As the machines are only used for plunge grinding table traverse and associated equipment has been dispensed with—this, it is stated, reduces the required working area by about 30 per cent when compared with conventional machines. Many of the machine characteristics and mechanisms are similar whether incorporated in a grinder arranged for straight or angular wheelhead approach and as the hydraulic and electric control systems used are uniform maintenance problems with a group of machines are minimised. The electrical control equipment, enclosed in cabinets which can be placed at any convenient point near a machine, is of straightforward simple design and means of rapid fault detection and rectification are provided.

A typical plunge grinding machine of unit construction together with one associated with automatic work handling and conveyor equipment are illustrated on this page. The front base unit round which each machine is built has a table of the required length capacity and is provided with the basic electrical control panel and other standard equipment. Any of four wheelhead base units complete with its feed drive mechanisms can be fitted on the rear of the base and the designs available include one for a straight wheel approach and three others for 10 deg., 30 deg. or 40 deg. angles respectively. The wheelhead and infeed units for fitting on these bases are complete with underslide, withdrawal cylinder, compensating mechanism, feed control valves, &c. They have a 4in travel with a maximum 0·100in feed and are available with either single- or two-stage feed or with an extended plunge (4in maximum) with either single- or two-stage feed.

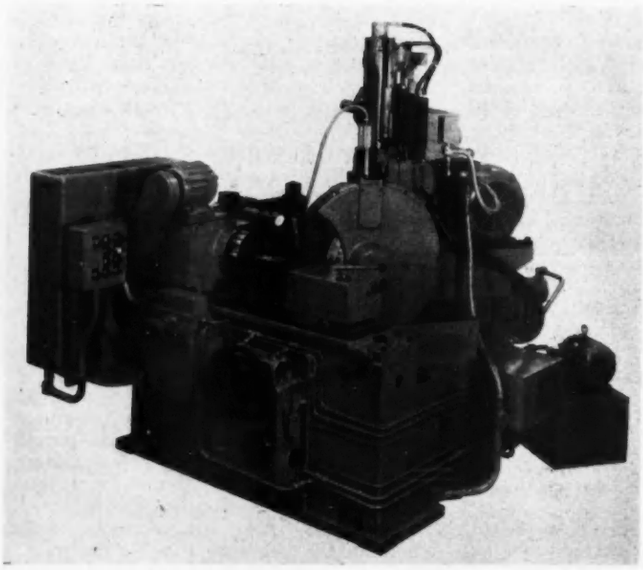
To cover a full range of work requirements any of five standard workhead units can be fitted on the table and they include single- and multi-speed live and dead centre designs and one with a single speed dead centre with a sliding centre. Both manually and hydraulically operated tailstocks are available as well as two-point manual hydraulic worksteady units. Diamond dressing units complete with control and compensating equipment are supplied for use with each of the straight or angular approach wheelheads. For automatic sizeing purposes there can be supplied either a wheelhead mounted, steady mounted or table mounted " O.M.T.-Etamic " equipment. Through the medium of this two-stage, electro-pneumatic equipment for the automatic control of component size and equipment for the automatic control of the machine operating cycle, repeatability to close tolerances is ensured.

Various types of conveyor and loading mechanisms have been developed to suit applications and customer preference and to adapt these " MU " machines for incorporation in link-line systems. The machine shown in one of our illustrations is fitted with a double arm overhead travelling trolley loading equipment which works in conjunction with a shuttling type conveyor specified by the purchaser. This equipment has a carriage to which are fitted twin arms housing gripping and lifting mechanisms. The carriage traverses a beam structure over the machine between the workpiece conveyors and the machine loading position.

In a typical automatic cycle with one of these machines a workpiece is first located on the workhead by advance of the tailstock centre or, alternatively, by a loading plunger. Rotation of the workhead then commences, coolant flow starts and rapid approach of the wheelhead ensues. At this stage a coarse grinding feed is automatically applied and, at a set dimension, a combined worksteady and " O.M.T.-Etamic " pneumatic gauging unit advances to contact the workpiece ; the grinding feed rate is then reduced and continues until the diameter is 0·001in from finish size. At this point the gauging and control system actuates a solenoid valve which puts into effect the finishing feed. When the requisite size is reached a further signal is transmitted to cause rapid retraction of the wheelhead, halt of coolant flow, clearance of coolant pipe from the workpiece and to stop workhead rotation. Finally, retraction of the tailstock or loading plunger results in the workpiece being ejected on to the vee supports. The unloading arm then descends, takes up the component and the loading arm positions a new workpiece on the vee supports. As this arm reaches its original position the machine cycle recommences. Simultaneously the loader carriage returns to a location above the " pick-up " point and the loading and unloading arms descend to take up a new and release a machined component respectively. Both arms then return to their initial situation and the carriage traverses to a position over the machine where it rests until it receives a signal to advance.



Special-purpose unit-built plunge grinding machine arranged for automatic production in association with work loading and conveying equipment



Plunge grinding machine of unit construction and having angle approach wheelhead and automatic sizing control

Fluid Bearings for Strip Processing Lines

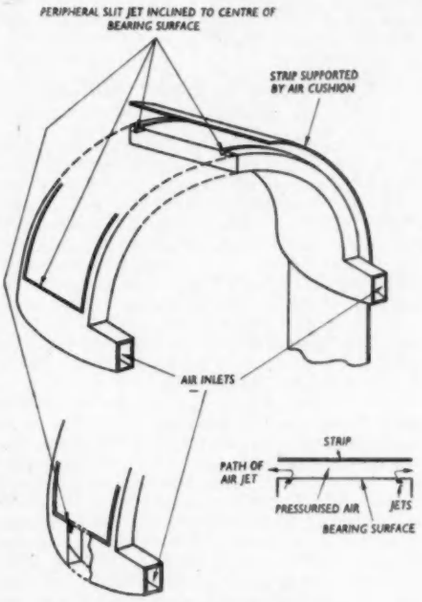
CONTINUOUS strip processing lines employ anything from seventy to 150 guide rolls, of which a high proportion must be driven, to provide the correct tension in the strip. With very thin strip (for example, ultra-thin tinplate) the design of the guide rolls and of the electrical control gear becomes complicated if strip breakage is to be avoided and surface damage minimised. The problem is accentuated by the increase in the speed of processing lines which is now being demanded. Consequently, the cost of the roll drive and control gear can be a very high proportion of the total cost of the line.

The British Iron and Steel Research Association has investigated the problem and has developed a strip guide which dispenses with rotating rolls and uses instead a controlled cushion of fluid between the guide surface and the strip itself. The cushion is formed by injecting a quantity of low-pressure gas or liquid between the guide surface and the strip. In principle, the device is similar to that used in the hovercraft in that a pressure rise occurs within the area bounded by annular jets, if these jets are in close proximity to a boundary surface. There is a great reduction in friction losses, and the elimination of rolls with high moments of inertia means that less power is required to move the strip. In addition, the strip need not be under high tension, as it has to be when conventional rolls are used, in order to preserve correct tracking through the line. Moreover, since there is no contact with the guiding surface, there is no risk of surface damage to the strip.

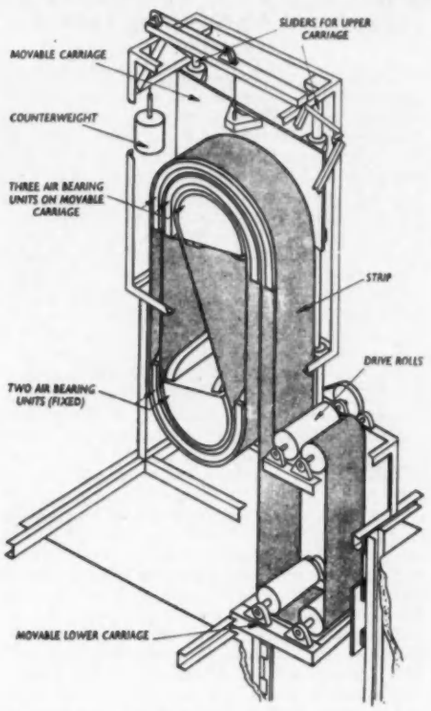
In designing the guides B.I.S.R.A. has deliberately kept the air pressures to within the capabilities of a fan, which is relatively cheap to install and maintain. Some typical experimental figures show that a single semi-cylindrical air-cushioned bearing of 2ft diameter, to support 36in wide tinplate under a tension of 150 lb, requires an air supply of 980 cubic feet per minute, at a pressure of 27in water gauge. This is equivalent to a fan horsepower of about 9 b.h.p., allowing for duct losses and fan efficiency.

Fluid cushioning systems offer possibilities of novel and more compact forms of plant design, leading to a reduction of capital costs. One such novel design is the labyrinth looping tower devised by B.I.S.R.A., which is illustrated herewith. A pilot scale tower, using strip 12in wide, has been operating in the Association's laboratories for the past six months. A similar arrangement can be used for the support and guidance of strip in a liquid processing tank, whereby a given length of strip can be accommodated in a tank of smaller volume than that required for a conventional serpentine arrangement.

The Head Wrightson Machine Company Ltd., Middlesbrough, has worked closely with B.I.S.R.A. in the latter stages of development of the fluid bearing, and has now been granted an exclusive licence to manufacture the device.



Typical air-pressure bearing



Air-pressure bearings applied to experimental labyrinth looping tower

An experimental rig has been built by Head Wrightson incorporating four air bearings, from 12in to 36in diameter and one 18in diameter liquid bearing which can be run partly or fully submerged. The rig operates with a closed loop of strip 32in wide and 150ft long, and strip speeds can be varied up to 2000ft per minute. Development work is proceeding to improve the performance of the bearings and to study problems peculiar to the type of processing line in which the bearings can be used.

Experimental rig at B.I.S.R.A., using fluid bearings in a looping tower

Technical Reports

Potential Flow Through Spiral Casings. By N. Athanassiadis. Zurich: Verlag Leemann A.G., Arbenzstrasse 20, Zurich, Switzerland. Price SF.30.—Spiral casings were developed in connection with the Francis turbine, but form also an important component of centrifugal pumps and blowers. The present paper deals with an investigation by means of electrical analogy, of two- and three-dimensional potential flow through spiral casings.

Theoretische und experimentelle Untersuchungen über die Lüftungsanlagen von Strassentunneln. By A. Haerter. Mitteilungen aus dem Institut für Aerodynamik an der Eidgenössischen Technischen Hochschule, No. 29. Zurich: Verlag Leemann A.G., Arbenzstrasse 20, Zurich. Price SF.20.—In the course of designing ventilation plant for road tunnels, the author came across certain hitherto unsolved problems which led him to undertake the present investigation. In particular, solutions are obtained for the size of the ventilation openings required for a given profile of the air intake, and the amount of air flowing along a duct of known velocity distribution.

Losning af Elasticitetsteoretiske Problemer ved Komplext Potential. By Ole F. Hastrup. Bulletin No. 13 of the Structural Research Laboratory, Technical University of Denmark. Copenhagen: Laboratoriet for Bygningsteknik, Danmarks Tekniske Hojskole, Kobenhavn.—Plane problems of the theory of elasticity may be solved by means of complex functions, as shown in the present report, for cases in which either the boundary stress or deformations are given. The solutions are checked by photoelastic methods.

SHORTER REPORTS

Opening of Manoeuvring Tank at Haslar

THE project to provide new facilities for the prediction and improvement of hydrodynamic performance of H.M. ships was approved by the Admiralty in 1953 and civil work began in 1954. Since then construction of the tank has proceeded and experimental equipment has been installed and the new manoeuvring tank, which has been fully operational for some time, was officially opened by H.R.H. the Duke of Edinburgh on Monday, December 18. After adding water from the Froude tank, to "mix the waters," the Duke visited the control room of the rotating arm, which was demonstrated, and then proceeded to the other end of the tank to witness manoeuvring tests. In these a self-propelled model of the guided missile destroyer H.M.S. "Devonshire" was put through certain evolutions under radio control and approached a speed equivalent to 28 knots for a ship. Following the manoeuvring tests the wave-making installation was put into operation and in the first demonstration the end units were run in unison to create a regular series of waves 30ft long by 12in high. These were allowed to die away and then both side and end wave makers were operated independently to create a confused sea in which the model was run to indicate the behaviour of a ship in such conditions.

The tank, which is fully enclosed, measures 400ft by 200ft and is 20ft deep and contains 40,000 tons of water. At one end is the tubular-steel rotating arm which has a radius of 100ft and can tow models up to 2000 lb in weight at any radius from 20ft to 90ft and at angular speeds from 0·01 to 0·6 radians per second. The wave-making plant is at the other end of the tank and consists of ten wedge-shaped steel plungers, each 6ft wide at the top and 17ft deep by 40ft long and weighing 29 tons when ballasted with 13 tons of water for the working condition. Five plungers are mounted end to end to form a 200ft continuous row across the end of the tank and the remaining five are disposed at right angles along the adjacent side of the tank.

Power Run on the Dounreay Fast Breeder Reactor

THE United Kingdom Atomic Energy Authority announced recently that its experimental fast breeder reactor had completed a run at power up to a maximum of 11,000kW on December 13. This power run followed a long period of work to overcome the problems of gas entrainment manifested earlier in the reactor coolant system.

Three sources of gas entrainment had been traced: the tubes used for guiding thermocouples into the lower coolant header; the control rod mechanisms; and, under peculiar conditions of blockage, certain by-pass circuits. Modifications have since been made to the thermocouple tubes and to the control rods, and liquid metal levels have been altered. Comprehensive instrumentation has been installed to monitor coolant levels in the by-pass circuits. Experiments have shown that there is now no significant reactivity change associated with the alteration of coolant flow, an original symptom of gas entrainment. Direct measurement of the pressure coefficient further confirms that no gas is now present even at full flow.

Confirmation of the success of these measures was obtained in a series of experiments at low power early in November. Then, on November 13 the heat output of the reactor was increased progressively to 1000kW and, next, in steps up to 8000kW on November 22. The reactor was run continuously at this power until the output was raised to 11,000kW on December 13. The power was then reduced, according to programme and the reactor was shut down for inspection.

At each step-up in the reactor heat output, experiments demonstrated the stability of the system on power changes. The reactivity oscillator has been in use over the same power range and no sign of instability has been detected. Power coefficients have proved constant over the range from 2000kW to 11,000kW and have agreed with those predicted by calculation. Concurrently with the above work a series of shielding experiments in the top shield of the reactor has given results consistent with those predicted in the design.

A Milestone in Boiler Making at Wolverhampton

THE ten-thousandth shell boiler to be made by John Thompson (Wolverhampton) Ltd. since sales records were kept, was dispatched by road to the customer, Rolls-Royce Ltd., on December 14. At a brief handing-over ceremony Sir Edward Thompson, chairman of the John Thompson Group of Companies, mentioned the long-standing relationship with Rolls-Royce. The first of many boilers supplied to this company by John Thompson was installed in 1907 and John Thompson Motor Pressings Ltd. has been supplying chassis frames for many Rolls-Royce cars since 1908.

After the handing-over, the boiler was towed away by a road locomotive which has been extensively used by John Thompson companies for the transport of heavy engineering equipment since 1929. The steam engine has three speeds and is sprung front and rear. A patent transmission plate ensures that the driving gears are always kept to the maximum depth when traversing rough ground. The original copper firebox is still in good condition and only recently passed a hydraulic test of 300 lb per square inch gauge by the insurance company. To-day the normal duties of this locomotive are confined to transporting heavy equipment between the fabrication shops at the Ettingshall works.

During a short tour of the Ettingshall works after the handing-over ceremony we were reminded of some of the developments in metal fabrication that have taken place in the past three decades. In 1934 John Thompson was one of the first two companies in England to receive Lloyd's approval for Class–I fusion welding. At about that time the Unionmelt submerged-arc welding process was introduced in the company's works. To-day, submerged-arc welding, with two runs only, of steel plate over 4in thick is commonplace. The work in hand includes a cylinder with a wall thickness of 7¼in being made to Class–I requirements. The firm has also done considerable development work on shielded-arc welding with CO_2. One application is in the welding of the boiler shells for Dungeness nuclear power station. John Thompson's share of this contract includes four boilers (the other four being supplied by Head Wrightson), all the gas ducting and the spherical valve casings.

V.L.F. Communications Transmitter

FURTHER details are to hand from Redifon Ltd. of the very low frequency transmitter for N.A.T.O. communications which is to be built at Anthorn, Cumberland (THE ENGINEER, December 1, 1961, page 931). When the tender was issued by the Post Office, Redifon Ltd. had already conducted discussions with the Ling Temco-Vaught Group in the U.S.A. on the possibility of co-operative activities in general. One member of the group is Continental Electronics Inc., and this firm has had experience in building the 2MW v.l.f. radio station for the U.S. Navy at Cutler, Maine. A co-operative approach was therefore agreed, and under the contract for the Anthorn station awarded to Continental Electronics Inc., that company is the prime contractor responsible for overall management and provision of the high-power amplifiers, while Redifon Ltd. is responsible for the highly stable drive equipment, and for the managerial and technical staffing in this country.

Transmission on v.l.f. in the range to be used at Anthorn (16 to 20 kc/s) has the property of following the curvature of the earth and is relatively little subject to daily and seasonal variations in propagation. It has the advantage of being capable of penetrating below the surface of the sea more readily than other means of radio transmission. Because it is also non-directional, it is an important medium of communication when steady and reliable signals are to be sent to nearby or remote destinations in any direction.

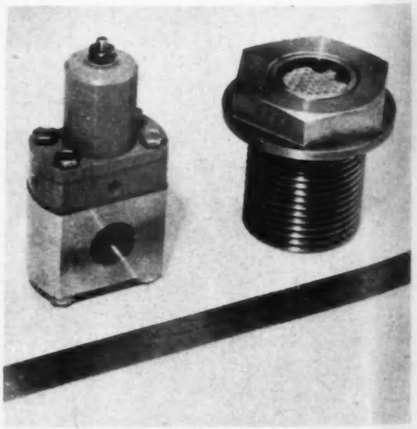
There are relatively few such stations operating in the world to-day, because the power needed is high, arising from the low frequency, and because the aerial system is necessarily physically small compared with the wavelength of transmission (some ten miles in this instance). The ground area needed and site requirements generally are difficult to satisfy. Anthorn will differ from most other stations of its kind in that the aerial system will be large enough to be capable of some 50 per cent or more of radiation efficiency, and so devised that a bandwidth of up to 150 c/s can be utilised, with a corresponding increase in the rate of communication. Frequency will be held constant to within one part in 100 million per month.

High-Pressure Relief Valve

A RELIEF valve for gas at high pressures has been made available by the Hymatic Engineering Company Ltd., Redditch, Worcs. Designated RAV 205, it may be set to any pressure between 3000 lb and 6000 lb per square inch and it will vent 25 cubic feet per minute at a nominal pressure rise of 200 lb per square inch from 4000 lb per square inch. The valve is less than 3in long and its basic weight is only 4 oz, it being constructed principally of aluminium alloy with a nylon valve seat and a stainless steel spring.

In addition to being available with ¼in B.S.P. male cone or banjo (illustrated) connections, the valve may be incorporated in a threaded plug; this form is recommended to safeguard reservoir cylinders which may be removed for charging, thus exposing any fittings to accidental damage.

[Reply Card No. 1503]



Two of the different versions of the high-pressure relief valve

Surface Roughness Comparison Scales

SURFACE roughness comparison scales to British Standard specifications for use in machine shops have been made by machining processes for a number of years by Rubert and Co. Ltd., Demmings Road, Cheadle, Cheshire. This firm has now introduced a complete range of electro-formed scales which consists of twelve different scales stated to represent every standardised value obtainable by the twelve basic machining methods. Flat specimen scales in the range cover the requirements for machining by lapping, grinding, linishing, end milling, face turning, shaping and planing, and horizontal milling; cylindrical specimens cover lapping and superfinishing, diamond turning, grinding, turning, reaming and drilling.

Each single scale is mounted in a moulded plastic frame marked with the respective value for C.L.A. in microinches and microns. Moulded on the back of the frame are instructions on how to obtain the best comparison results for the particular machining method, and a table giving the values for maximal depth and levelling or mean depth for each specimen. To avoid a machinist using the wrong set of specimens, an appropriate machining method is clearly marked on the frame and the frames are distinctively coloured.

The full set of twelve scales can be supplied in a box or each scale can be supplied singly or in any combination of two upwards in accordance with the machining operations involved.

[Reply Card No. 1527]

Measuring Thin Coatings

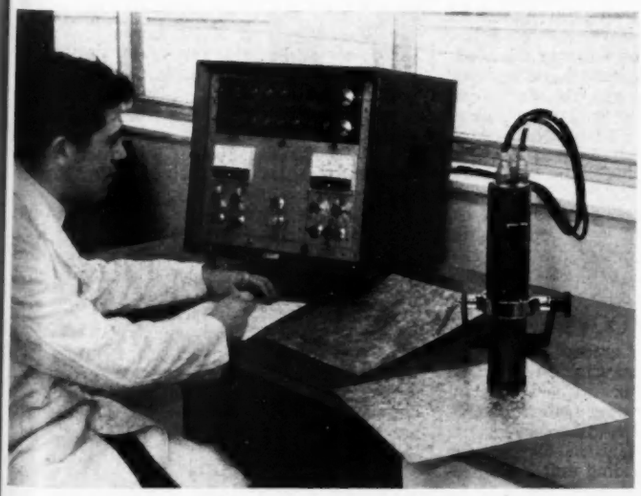
To provide accurate measurement of coatings on static samples where the coating thickness is below the minimum of a normal beta gauging system, a fluoroscopy gauge, Type N683, has been developed by Ekco Electronics Ltd., Southend-on-Sea, Essex. The gauge operates on the principle that an element, irradiated with a suitable source, emits X-radiation of a wavelength which is a characteristic of itself. Two basic techniques are used. In the first, the characteristic radiation of the coating only is measured and this varies in intensity with the coating thickness up to a saturation value. In the second technique, the characteristic radiation of the base material is excited, and the attenuation of this by the surface coating is dependent on the coating thickness. The first method has the advantage of greater accuracy and occupies less time for a given percentage accuracy when measuring extremely thin coatings such as paints on a metal base. The second method is more commonly used, however, providing better differentiation due to the double attenuation when the radiation enters and leaves the sample. Applications of the gauge include measurement of tinplate or zinc on a steel base; lacquer coatings on tinplate; silver halides in photographic materials; printability of various papers; paint films on metal base; and plastics films on various bases.

The main instrument of the gauge is a combined scaler and timer (seen on the left in the illustration) which incorporates a stabilised h.v. supply, a pulse height analyser and a high-gain input amplifier. Provision is made for connecting a proportional counter, or for using a standard scintillation counter as illustrated, which has been adapted for constant temperature operation.

In use, a small *Bremsstrahlung* source such as tritium or promethium is mounted in the centre of the counter window, and reflected radiation, which is proportional to the thickness of the coating, is counted. A locating ring on top of the counter gives correct source-counter distance and an accuracy of ± 1 per cent is obtained

In addition to making possible measurement of thin-coated layers previously outside the scope of beta backscatter gauges, the fluoroscopy technique has the further advantage that the area of measurement is much reduced. In some cases the measurement is semi-analytical, as in the determination of the quantity of silver present in photographic emulsions. The successful operation of the system is largely dependenon the careful choice of the most suitable *Bremsstra' lung* source for any given application.

[Reply Card No. 1521]

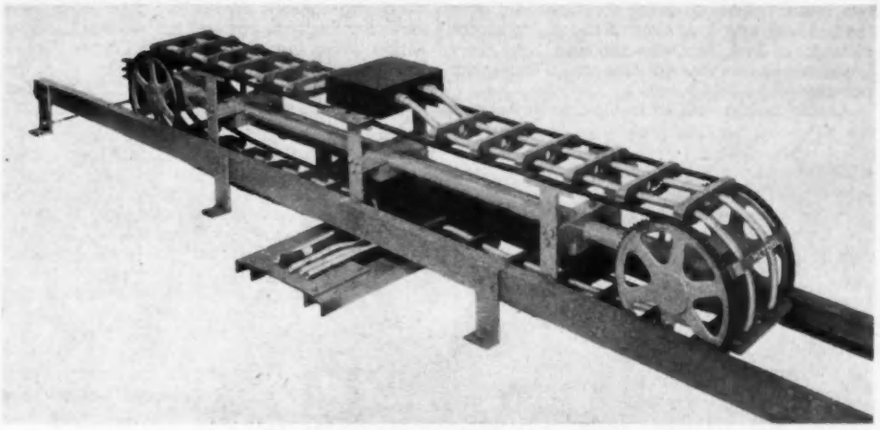


Measuring a thin coating on a metal base by X-ray fluoroscopy

Cable Chain Equipment

A CABLE chain equipment for carrying the trailing cables and hoses such as are required for connection of power supply and other lines to moving parts on large machine tools, cranes and mechanical handling plant has been introduced by Metropolitan Tool and Products Ltd., 21, Victoria Street, Nottingham. With these installations, one of which we illustrate on this page, the flexible lines are subjected to no tension, pressure, friction or other detrimental forces, and the bending which occurs falls within the maker's recommendations.

Each of the "Metool" cable chain systems comprises two roller chains connected at 6in pitches by cast aluminium spacers or cleats. The flexible elements lie in holes in these spacers, the centre line of the holes being coincident with the pitch line of the chain. The chains are endless and at the bottom half of their circuit there is fitted a terminal box which is firmly anchored at the centre point of the travel. This terminal box provides a means for connecting the incoming power and at the centre of the top half of the chain another terminal box is used for connecting the lines to the moving machinery. With this arrangement the upper terminal box can move right and left equal to a distance approximately twice the overall length of the cable chain.



Cable chain system for the feed and power lines of moving plant

The roller chains pass around a carriage consisting of standard sprocket wheels at either end of a beam incorporating means of adjustment to enable the chain to be tensioned to the required degree. Half the total number of cables or hoses are passed one way around the chain and the other half around the other so that the width of the unit is kept to a minimum. Movement is, of course, imparted to the equipment by the travelling machine to which power is being fed, and it naturally follows that the carriage moves at half the speed of the machine. The chain carriage runs on ball-bearing-mounted flanged wheels in a channel section track and the upper part of the chain is supported as necessary by jockey wheels or skids.

[Reply Card No. 1526]

High-Impedance Semiconductor Valve

DEVELOPMENT of a silicon semiconductor valve for use where a very high input impedance is required is announced by the Brush Crystal Company Ltd., Hythe, Southampton. This device, the OC 800, is basically a field-effect transistor analogous in performance to a thermionic valve. It has an input impedance in excess of 100 megohms, with a particularly low noise level. The device behaves like a valve, requiring very little current drive for considerable variation in output current (mutual conductance is typically 0·1mA/V). One potential use of the OC 800 is as a cathode follower in a conventional valve circuit for matching high input impedances to those normally required by conventional transistors, the input impedance of the device being about 700MΩ. Other applications for which the device is suitable include feeding from piezoelectric ceramic elements, tape heads, magnetic heads, pick-up and microphone cartridges, amplifier inputs, transducer matching and all low-noise input circuits. The OC 800 is a three-terminal device with connections to an anode, a cathode and a modulator electrode corresponding to the grid of a thermionic valve. It is contained in a canister 8·5mm high and 5mm in diameter, on a base 5·6mm in diameter.

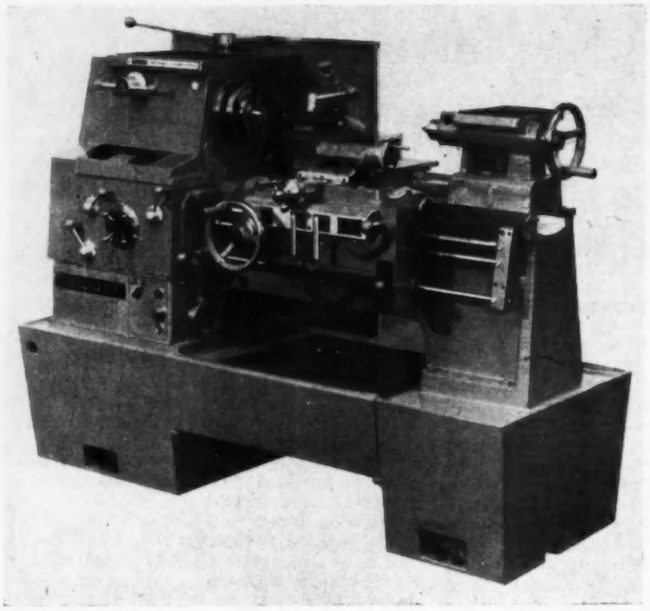
[Reply Card No. 1537]

SHORTER REPORTS *(Continued)*

High-Speed Lathe

A HIGH-SPEED geared headstock lathe which has been added to the range of machine tools manufactured by B. Elliott (Machinery) Ltd., Victoria Road, London, N.W.10, is made in two centre heights to swing 15in and 16in over the bed and with four sizes of bed giving centre distances of 24in, 36in, 48in and 60in. The clean functional lines of the new lathe can be seen in the photograph we reproduce.

A wide cabinet with an ample chip tray carries



High-speed geared headstock lathe

the deep cast-iron bed of the lathe and a short bridge at the headstock end can be removed to provide a 9in wide gap in which work up to 20⅜in diameter can be swung. Precision matched bearings carry the D.I.N. 6 flanged spindle with a quick change swash plate which facilitates speedy interchange of chucks and fixtures. The spindle has a 2⅛in bore through its length to clear 2in diameter stock and three alternative headstock drives are available. One headstock driven by a 4 h.p., 1500 r.p.m. motor provides twelve spindle speeds between 30 and 2500 r.p.m.; a second headstock driven by a 2½ h.p., 1000 r.p.m. motor gives twelve speeds between 20 and 1650 r.p.m.; and the third headstock is driven by a two-speed, 2½ h.p./4 h.p. motor to give spindle speeds between 20 and 2500 r.p.m. The eight lowest spindle speeds are transmitted directly through gears, whilst final transmission of the four higher speeds between 705 and 2500 r.p.m. is taken through timing belts. With this arrangement the maximum gear meshing speed, even when the spindle is driven at 2500 r.p.m., is below 700ft per minute. A pedal-operated brake is provided for rapid stopping of the spindle.

To avoid overspeeding of the feed drive through the change gears, and possible damaging of the feed box in the event of simultaneous engagement of a high spindle speed and a high feed rate, the feed drive speed is automatically reduced by 4 to 1 when the high range of spindle speeds is engaged. Through the feed gears 108 thread and feed changes are available, the sliding feeds ranging from 0·0007in to 0·021in and the surfacing feeds from 0·0005in to 0·015in per spindle revolution. With the dial change feed box fitted all standard threads from 1¼ to 80 per inch are directly obtainable in forty-five changes and 0·1875mm to 10mm in twenty-four changes. By a single change in gearing a wide range of module and diametral pitches can be cut. The drive to the leadscrew is isolated when it is not required for screw-cutting.

The saddle has a totally enclosed double wall apron with oil bath lubrication and a shear pin is fitted after the main reduction gearing in the drive to protect the transmission in the event of overload is quickly replacable. The sliding and surfacing feeds are engaged by two vertical snap action levers, hinged at the centre upper part of the apron and controlling toothed clutches in the drives. A full length cross slide with a travel of 11in carries a swivelling tool slide which has a travel of 4¼in and is designed to take 1in square tools in a ratchet indexing four-way tool post. When a saddle micrometer stop unit is fitted to special order for dead stop working a Nylon overload slipping clutch replaces the shear pin assembly so that the drive can slip at the stop position. A taper turning attachment is available for the lathe and a telescopic arrangement of which the cross slide screw forms part enables the operator to retain manual control of the slide during turning of taper work.

Particular care has been taken in the design to give ease of access to all mechanisms for maintenance purposes and a control box containing all the switchgear can be removed as a complete unit by releasing two screws and withdrawing a multi-point plug. This box contains the no-volt release, mechanically interlocked reversing contactors, &c., and when its rear cover is removed the switchgear is fully accessible for checking. When it is required to inspect the interior of the headstock its top cover can be removed and the gear change lever replaced to operate the glut movements. The headstock lubricating oil pump, which also supplies cooling oil to the matched spindle bearings, can be removed without disconnecting any of the piping. Any shaft in the headstock can be removed without disturbing any other parts of the mechanism and main vee belt adjustment is effected from outside the cabinet by means of two screws.

[Reply Card No. 1524]

Power Source for CO_2 Welding

CONTROL of the arc characteristics during welding independently of the voltage is provided by a variable choke stabiliser in a new constant voltage selenium rectifier power source for CO_2 welding announced by the Lincoln Electric Company Ltd., Welwyn Garden City, Herts. Basically, this CVR.200 welding unit is a three-phase, natural air-cooled, constant-voltage transformer-rectifier providing a voltage range of 14V to 30V d.c. and a continuous output of 200A d.c. at 25V (5kW), with an input of 415V. Voltage selection is provided in a series of sixteen steps of approximately 1V by means of coarse and fine switches. These are seen in the

Welding power unit with independent voltage and arc stabilisation controls

illustration to left and right of the central handwheel for operating the stabiliser. By means of this device it is claimed that greater sensitivity of arc control is obtained than by voltage adjustment alone, inductance being added to the circuit as required to minimise spatter loss.

The CVR.200 is of all-welded steel construction and is mounted on castors with 5in diameter hard-rubber wheels. All panels with the exception of the front panel can be removed without any of the internal wiring having to be disconnected. It is intended primarily for use with the Lincoln "Sprite" CO_2 semi-automatic hand-welding unit, and can be supplied in a special version with the "Sprite" unit mounted on top of the CVR.200 on a turntable.

[Reply Card No. 1520]

General-Purpose Battery

WHEN the Exide "Keepalite" P portable emergency lighting equipment was introduced last September by Chloride Batteries, Ltd., Exide Works, Clifton Junction, Manchester, it was powered by a battery with low open-circuit losses which had been specially developed for this purpose. This Exide 6V battery, type 3-CB5, is now available for general use and will cover a wide range of duties including intermittent and stand-by functions such as burglar and fire alarms, and others where the battery will be maintained under floating or trickle charge conditions. The 3-CB5 battery is also suitable for duties which involve fairly frequent discharging and re-charging.

The three-cell battery is assembled in a white, translucent, high-impact polystyrene container which enables the electrolyte level to be seen. Maximum and minimum levels are indicated by red lines on the container. The cover is moulded in black, high impact polystyrene and is cemented to the container. Rectangular lug terminals, each with a lead-plated nut, bolt, and washer, are fitted and are suitable for use with spade cable ends. Capacity of the 3-CB5 battery is 14 Ah at the 20h. rate. Measurements are 3⅞in long by 4⅜in wide by 7 1/16in high, and it weighs 9 lb filled.

[Reply Card No. 1540]

Optical Alignment Instrument

THE "Rodolite" aligning instrument, introduced by Cooke Troughton and Simms Ltd. (a member of the Vickers Group), Haxby Road, York, is based on the circular diffraction grating alignment device developed at the A.E.I. Research Laboratory (Patent No. 862290) It is an optical instrument consisting of two elements, a circular diffraction grating in an adjustable mount, and a sighting head. It will define a straight line to within 0·0001in in 20ft and

"Rodolite" and target set up for checking column alignment on gear hobber

enables errors of alignment to be readily determined.

The target, consisting of a diffraction pattern of equally-spaced bright and dark rings, remains in focus without adjustment at any spacing from 6in to 20ft, and x and y displacements can be read directly from 0·0001 micrometer drums. There is no parallex error, since the setting is made on a diffraction grating which is continuously in focus, and the initial adjustment is simple owing to the large field of view.

For some applications it is desirable to establish a line which is not only straight but vertical. This can be done by using, instead of the ordinary diffraction grating target, a mercury pool target, in which the grating is fixed close to the surface of a shallow pool of mercury. This behaves as a reflection grating which is always horizontal; hence the line defined thereby is always vertical.

[Reply Card No. 1535]

3-ton Hydraulic Mobile Crane

A HYDRAULICALLY-OPERATED mobile crane of 3 tons capacity is now being made by Tunny Cranes Ltd., Abbey House, Victoria Street, London, S.W.1. Fitted with a 16ft jib, this crane is designed to lift 3 tons at 7ft radius, giving a height of lift of 17ft under the hook from 4ft above ground. It is capable of raising 2 tons at 9ft radius and 1 ton at 14ft 9in radius. When a 10ft extension is fitted to the jib the lifting rated capacity is 1¼ ton at 8ft to 10 cwt at 20ft radius. A maximum hoisting speed of 60ft per minute is available.

The crane is powered by a Fordson "Super Major" four-cylinder diesel engine which develops 51·8 b.h.p. at 1800 r.p.m. Hydraulic power for operating the hoisting, derricking and slewing motions is provided by a Vickers vane pump, driven off the engine crankshaft through a flexible coupling. This pump maintains a system pressure of 1550 lb to 1650 lb per square inch, and has a rated capacity of 8 g.p.m. at 1500 r.p.m. The pump delivers to a control circuit through a relief valve which prevents overloading of the pump and system. Manually-operated directional valves grouped in front of the driver's seat are used for movement selection and speed control.

The cylinders of the crane motions are double-acting, and hydraulic locks are provided in the hoist and derrick cylinders so that in the event of power failure the pressure is maintained and the load held in position until released by an overriding manual control.

Hoisting is effected by a 5in bore, 60in stroke cylinder working within the jib frame in association with a six-sheave pulley arrangement. The derricking cylinder is 4½in bore by 35in stroke, and the time taken for maximum-to-minimum derricking is twenty seconds. The slewing cylinder operates a rack meshing with a pinion at the base of the king post and gives a slewing arc of 300 deg. For travelling purposes the drive from the engine is transmitted through a hydraulically-operated gearbox having six speeds forward and two reverse, the maximum road speed being 15 m.p.h. Stabiliser outriggers are fitted for 3-ton ratings with the jib in positions other than over the front of the vehicle.

[Reply Card No. 1485]

Numerically Controlled Precision Dividing Table

AT a recent demonstration arranged jointly by Societe Genevoise d'Instruments de Physique and E.M.I. Electronics Ltd., Hayes, Middx., there was shown a "Rotoptic" 6CN dividing table operated by "Emicon" rotary positioning equipment with punched tape control. The 31½in diameter dividing table is claimed to have a positional accuracy of ±2 seconds at any point in the circle, with automatic indexing. It it mounted on a plain central bearing and supported on an outer annular ball track, its normal permissible load being 2200 lb, but under special conditions it will take workpieces weighing up to 3300 lb. In addition to electronic numerical control, this table can be equipped with a direct reading optical measuring system as is shown at the side of the table on the jig boring machine in our illustration.

The punched tape used with the electronic numerical control equipment can be either of standard $\frac{11}{16}$in wide five-channel or of 1in wide eight-channel paper strip. This tape takes up to thirty-one codes and is prepared in terms of degrees, minutes and seconds. With numerical control by punched tape all that is required of the operator at each required indexing is depression of a control knob, after which unlocking, indexing, and re-clamping of the table is automatically effected. Alternatively the equipment can be switched to automatic indexing to positions indicated by manual settings of degrees, minutes and seconds on dials on the control console.

The equipment incorporates two measuring systems for numerical control purposes. In the first system a resolver transforms the angular position of the table platen through 360 deg. to an analogue a.c. voltage and controls automatic indexing to within 0·5 deg. from the prescribed position. The second system comprises a 12in diameter "Inductosyn" which ensures the final positioning to within two seconds of arc. Two motors turn the table—a squirrel-cage motor for rapid rotation and a servo motor which gives final indexing. When the angular movement to be imparted exceeds 5 deg. the squirrel-cage motor is switched on by a relay, whilst below this value the servo motor alone controls the table indexing movement.

The makers state that this automatic tape-controlled table indexing system can be integrated with the numerical co-ordinate control systems fitted to G.S.I.P. jig boring machines.

[Reply Card No. 1488]

Dividing table with automatic numerical control fitted on a jig boring machine

Flexible Joint for Stoneware Pipes

A FLEXIBLE joint known as "Drawflex" which enables salt-glazed vitrified pipes to be securely and permanently connected without the use of cement either for jointing or bedding has been developed by Doulton and Co. Ltd., Doulton House, London, S.E.1. Initially the use of this joint is limited to 4in to 9in diameter pipes. It enables each joint along a pipe run to flex freely in any direction up to a maximum angle of 5 deg. and be telescoped or drawn by as much as ¾in while withstanding satisfactorily an internal or external pressure of 20 lb per square inch.

Joints are made by the simple process of pushing the spigot on one pipe into the socket of another using soapy water as a lubricant.

The sealing element used comprises resilient plasticised P.V.C. rings moulded on the spigot and in the annulus of the socket, the design being such that when the pipe connection is made the two seals are pressed together with a high-compression zone in the centre. The rings are resistant to the effects of chemicals normally found in effluents, sewage or soil, and to bacteria and root penetration.

[Reply Card No. 1495]

Motor Industry Summer School

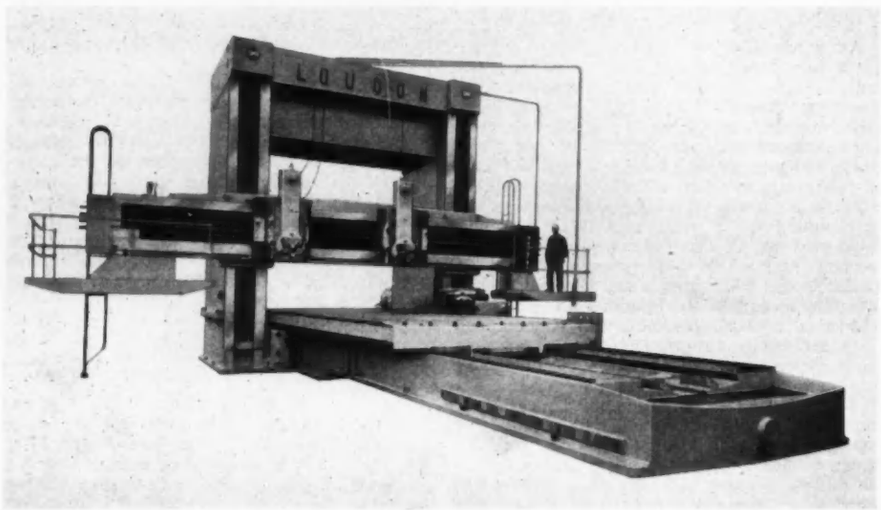
THE sixteenth annual summer school of the Institute of the Motor Industry will be held at Queen's College, Cambridge, from August 17 to 24, 1962. The programme of lectures covers a range of subjects of importance to management, including presentation of technical information. The fees, including residence in the College, are 18 guineas to members of the Institute and 20 guineas for non-members. Enrolment forms are available from the Secretary, Institute of the Motor Industry (Inc.), 40, Queen's Gate, London, S.W.7.

SHORTER REPORTS *(Continued)*

Large Planing Machine

We illustrate one of the largest planing machines built by Scottish Machine Tool Corporation Ltd., 17, Lynedoch Crescent, Glasgow, C.3. This double-housing machine is capable of planing workpieces up to 12ft wide, 10ft high, and 26ft long. It is driven by a closed-loop Ward-Leonard equipment incorporating a variable speed d.c. main driving motor developing 120 h.p. at mid-speed and 240 h.p. at maximum speed. This system offers a number of advantages by giving quick acceleration to the selected speed, control of the speed during intermittent cutting, and a wide range of available speeds (approximately 50 : 1). The machine, with a double-spiral drive, has a maximum table speed of 200 feet per minute, but it is provided with a back gear which offers a second speed range up to 120 feet per minute.

The bed has two broad flat surfaces to support the table. The inside edges of the bedways provide a long narrow guide for the table, which is fitted with replaceable plastic-lined ways. Lubrication of the bedways is by a motor-driven pump, the delivery of which can be varied to suit working conditions. Surplus oil from the bedways flows down inclined faces to a central channel in the bed, in which a long filter strip is fitted, and on through secondary filters to the central oil tank.



Planing machine for work up to 26ft long by 12ft wide by 10ft high and having a maximum table speed of 200ft per minute

The table, uprights and cross-tie of the machine are all internally stiffened by lattice ribbing. A deep cross-rail carries a separate screw and feed shaft for each toolbox so that they can be controlled independently from the end of the cross-rail. The down feed slides incorporate solenoid-operated tool relief. Micrometer dials are provided on the screws and the electrical controls on the pendant include one by which accurate setting of the tools can be effected under power. The feed motor is of 10 h.p. and the cross-rail elevating motor is 15 h.p.

Although the machine, as illustrated, has only three toolboxes, a rear side box can be fitted at a later date if required. As the planer is designed to work with a powerful milling head, an auxiliary drive to the table is provided by a separate 12½ h.p. driving unit giving infinitely variable speeds from 1in to 56in per minute. A 3 h.p. drive on the cross-rail gives cross feeds of 1in to 21in per minute and each of these motions is engaged by a clutch which automatically disengages the regular drive or feed used for planing.

[Reply Card No. 1506]

Oxygen Concentration Measurement

Two forms of meter for measuring oxygen concentrations by magnetic separation are announced by the Cambridge Instrument Company Ltd., 13, Grosvenor Place, London, S.W.1. They are largely complementary and together have a wide range of industrial applications, especially in the measurement of oxygen in boiler and cement flue gases.

The meters are either of the annulus or filament form. Use of the annulus form is recommended for oxygen estimations where more than 1 per cent hydrogen or helium is present, or where a high speed of response is desirable. In this meter the gas flows round an annulus in a brass block, with a thin-walled glass tube fixed across its horizontal diameter. A platinum heating coil wound round the outside of the tube is centre-tapped so that its two sections form two arms of a Wheatstone bridge. One end of the tube is in the field of a powerful magnet. Oxygen is attracted by the field into the tube, and on passing through the latter is heated by the external coil. Its paramagnetic susceptibility is reduced with rising temperature, so that the attraction remains higher at the edge of the field which is outside the heated zone. As a result a pressure difference is built up across the field and gas flows through the tube, the flow being maintained by the continuous attraction of unheated oxygen. The incoming gas flow cools one section of the heating coil more than the other, so that the balance of the Wheatstone bridge is upset and a current flows which deflects an indicator or recorder calibrated directly in oxygen percentage.

The annulus instrument is affected by carbon dioxide and must be used in a level position. On the other hand the filament form of analyser is comparatively insensitive to carbon dioxide and is more suited to conditions where change of level is involved, as in seagoing ships. In the filament analyser two heated glass-covered platinum filaments are mounted in two cavities in a metal block. One is cooled by a flow of oxygen attracted into the cavity by a magnetic field as before. The resultant change of resistance unbalances a Wheatstone bridge, again causing operation of an indicator or recorder.

The analysers are fitted with flow gauges and can be equipped with motor-driven aspirators if the gases to be sampled are not under pressure.

[Reply Card No. 1530]

Automatic Rail Brakes for Mine Cars

As a result of five years' successful use of the "Hydrabrake" device developed for controlling the speed of main-line wagons on gradients, Strachan and Henshaw Ltd., of Bristol, has now introduced a smaller version of these rail brakes for installation on narrow-gauge mine-car tracks in underground workings.

This mine-car "Hydrabrake" is a compact simple device having a pivoted arm with a pad at each end, as can be seen in the illustration below. An integral tooth projecting down from the arm, immediately under the pivot, engages in a slot in a double-headed piston working in opposed horizontal cylinders which are filled with oil. Passages through the piston connect the two cylinders. When a mine car passes over the brake, the wheel flange depresses the leading pad to move the piston along the cylinder and bring the trailing pad up into position. This trailing pad is then depressed in turn by the wheel, moving the piston back and setting the arm ready for the next wheel.

One of the passages in the piston connecting the two cylinders is fitted with a restricting orifice which allows oil to pass from one cylinder to the other at a controlled rate as with a conventional dashpot. The orifice is so selected that no resistance to movement in successively depressing the pads is imparted to a vehicle moving at low speeds, but, as the speed increases, so the resistance to the motion of the piston—and, therefore, the braking force exerted on the car—increases. Two further passages in the piston are fitted with over-pressure release valves—one for operating in each direction—and these valves open to release oil to the other end of the piston if the speed of approach of a car is high enough to produce a downward force on the arm in excess of the designed figure. In this way, lifting of the car wheel is prevented, but the brake still absorbs the designed amount of energy. A further passage in the piston connects the cylinders with a central oil reservoir fitted with automatic refill valves to ensure that the pressure system is always completely filled with oil.

The brakes are fixed to the web of the rail on the inside by only two bolts, and they are fitted between sleepers. It is, therefore, a simple matter to adjust the braking on a given circuit to give the best results, by the addition or removal of brake units. These brakes, which are sealed units requiring very little maintenance and no adjustment, are available for fitting to 35 lb, 50 lb or 60 lb flat bottom rails.

[Reply Card No. 1505]

"Hydrabrake" bolted to the inside of the rail web and showing the rocker arm and the two pads which contact the flange of the car wheel

PERSONAL AND BUSINESS

Appointments

MR. JOHN G. BRICKNELL has joined Hedin Ltd. as Midland area representative.

MR. C. R. WHEELER has been appointed chairman of the British Standards Institution's export panel.

MR. L. J. FORD, M.I.Prod.E., has been appointed general manager, works services, by Creed and Co. Ltd.

MR. W. G. LISLE, A.M.I.Mech.E., A.F.R.Ae.S., has been appointed chief engineer of Mitchell Hydraulics Ltd.

FLUIDRIVE ENGINEERING COMPANY LTD. has announced that Mr. John Raymond, M.I.E., has joined its board.

DR. G. ADER has been elected chairman of the Reinforced Plastics Group Steering Committee of the Plastics Institute.

DENIS FERRANTI COMPANY LTD., states that Mr. R. Cookshoot, general manager, has been appointed a director of the company.

GLENFIELD AND KENNEDY LTD. announces that Dr. P. L. Boucher, chief civil engineer, has been appointed a director of the company as from January 1, 1962.

MR. S. SHEPHERD-SMITH, managing director of Austin Hoy and Co. Ltd. has been appointed to the board of the parent company as from January 1, 1962.

MR. H. LEE BUSCH has been elected a director of Vauxhall Motors Ltd. He has been managing director of General Motors Ltd., London, since April 1 this year.

THE INCANDESCENT GROUP announces that following the death of Mr. R. D. Macmillan, Mr. A. Derbyshire has been appointed managing director of Controlled Heat and Air Ltd.

SIR JULIAN PODE, deputy chairman and managing director, The Steel Company of Wales Ltd., will succeed Mr. C. R. Wheeler, as President of the British Iron and Steel Federation on January 1, 1962.

MR. JAMES BUCKMAN, A.M.I.Mech.E., M.I.Prod.E., formerly project development manager of the Standard Motor Company Ltd., has been appointed general manager of the Bridgwater Machine Company Ltd.

BRITISH INSULATED CALLENDER'S CABLES LTD. announces that Mr. F. C. Walmsley, M.I.E.E., Mem. A.I.E.E., is joining the company on January 1, 1962, as assistant divisional manager, capacitor division.

MR. J. A. FITZPATRICK has been appointed northern area manager at Manchester of Cape Insulation and Asbestos Products Ltd. in succession to Mr. J. F. Callaghan who retired on December 1 after forty-one years with Cape Asbestos.

BELLING AND LEE LTD. announces the appointment of two executive directors. Dr. A. C. Robb, A.M. I.E.E., formerly technical manager now becomes technical director, and Mr. J. R. Turrill formerly sales manager becomes the sales director.

THE BRITISH INDIA STEAM NAVIGATION COMPANY announces that Mr. Charles Stephen Mundy, a managing director of the company, has retired from the board. Mr. Andrew James Maitland-Makgill-Crichton has been appointed director of the company as from December 14, 1961.

MR. F. H. BEASANT, M.I.E.E., M.I.Mech.E., M.I.Loco.E., has been appointed Manager-Traction of Brush Electrical Engineering Company and has now moved from the company's London office to Loughborough to take up his new post. He has been deputy manager since joining Brush in 1959.

THE DISTILLERS COMPANY LTD., announces that with effect from January 1, 1962, Mr. J. S. Hunter, at present assistant managing director (commercial) of the D.C.L. chemical division, will be transferred to assist the chairman of the D.C.L. chemical group at 21, St. James's Square, S.W.1. He will remain a division director of the D.C.L. chemical division, but without executive responsibility, and will be appointed an alternate director of British Hydrocarbon Chemicals Ltd., Grange Chemicals Ltd., Forth Chemicals Ltd. and Murgatroyd's Salt and Chemical Company Ltd.

BRITISH TRANSPORT COMMISSION announces that with effect from January 1, 1962, Mr. H. C. Johnson, at present general manager of the Eastern Region of British Railways, has been appointed to succeed Mr. David Blee as general manager of the London Midland Region. Mr. Blee retires from the Commission's service on December 31, 1961. Mr. J. R. Hammond, at present general manager of the Western Region of British Railways, succeeds Mr. Johnson as general manager of the Eastern Region, and Mr. S. E. Raymond, at present traffic adviser at the Headquarters of the Commission, succeeds Mr. Hammond as general manager of the Western Region. On January 1, 1962, the general manager of each of the railway Regions will be appointed a member of the appropriate area board.

BRITISH INSULATED CALLENDER'S CABLES LTD., has announced that in view of the growth in the activities of the B.I.C.C. Group in recent years the chairman, Sir William McFadzean, in order to be free to concentrate on overall policy and the national and international aspects of Group affairs, is at his own request relinquishing the office of managing director whilst remaining executive chairman. In this capacity he will remain responsible to the board for supreme executive policy and the overall coordination of the company and Group, but will delegate the executive operation to Mr. R. M. Fairfield and Mr. W. C. Handley, at present assistant managing directors, who will become joint managing directors. Mr. H. F. Akehurst, at present assistant managing director, will become executive director (export) and Mr. W. Fraser, at present a director, will become executive director (overseas companies). The foregoing takes effect from January 1, 1962.

Business Announcements

AMF LTD. announces that it has acquired the entire share capital of Bennis Thermoflash Ltd. The company has been renamed Thermoflash Ltd.

BRITISH INSULATED CALLENDER'S CABLES LTD. states that B.I.C.C.-Burndy Ltd., has moved from Prescot, Lancs., to larger premises at Parr Industrial Estate, St. Helens, Lancs. (telephone, St. Helens 6251).

SQUARE D LTD. has announced the opening of a new branch office at Druelyn House, De-La-Beche Street, Swansea, to service the needs of the steel and general industry in South Wales. Mr. R. A. S. Richardson has been appointed branch manager.

THE PLESSEY COMPANY LTD., Ilford, Essex, has concluded a licence agreement with Illinois Tool Works Inc., Chicago, and its subdidiary, ITW Ltd., Slough, Bucks., whereby Plessey will manufacture and market Licon R precision snap-action switches in the United Kingdom.

B.S.A. TOOLS GROUP LTD. announces that from January 1, 1962, the United Kingdom sales representation for The Churchill Machine Tool Co. Ltd., Broadheath, Manchester, will be carried out by Burton Griffiths and Co. Ltd., Mackadown Lane, Kitts Green, Birmingham, 33.

PHOTRONIC CONTROLS LTD. announces the appointment of Perfection Parts Ltd., 59, Union Street, London, S.E.1 (telephone, HOP 4567), as sole stockist for the following controls : smoke alarm type SA, smoke indicator type SI, and oil burner sequence and flame failure control type OB1.

THE MINISTRY OF TRANSPORT states that the work of the Mercantile Marine Office, Milford Haven, will be transferred from H.M. Customs and Excise to the Ministry with effect from January 1, 1962. The address of the new office will be Point Street, Milford Haven (telephone, Milford Haven 1188).

PRE-PILING SURVEYS LTD. has moved its headquarters from 28, Victoria Street, Westminster, London, S.W.1, to 7, Gower Street, London, W.C.1, (telephone MUSeum 1801). With effect from the end of this year the company is extending its overall service to include chemical pressure grouting of soils, installation of bored type piles, where ground conditions permit, installations of vertical sand drains and the establishment of a section to undertake the drilling of reinforced concrete and other building materials.

SWAN, HUNTER AND WIGHAM RICHARDSON LTD. announces that it has acquired for cash the entire issued share capital of Brims and Co. Ltd. civil engineering contractors, of Newcastle upon Tyne. This company, therefore, becomes a wholly-owned subsidiary of the Swan Hunter Group. The present directors of Brims and Co. Ltd. will be retained in their respective capacities. The board will be constituted as follows : Mr. E. J. Hunter, chairman, Mr. D. V. Brims, managing director, Mr. S. Turnbull, Mr. C. P. B. Goldson, M.I.C.E., Mr. A. Walker, M.I.C.E., The Hon. N. Ridley, A.M.I.C.E., The Rt. Hon Lord Howick, Mr. Sheriton C. Swan.

Contracts

THE HEAVY PLANT DIVISION OF ASSOCIATED ELECTRICAL INDUSTRIES LTD. has received orders worth nearly £440,000 from Stewarts and Lloyds Ltd. for electrical equipment at the latter company's Corby Works, where No. 1 continuous hot strip mill is being modified and a new 20in bar mill is being installed. A.E.I. will supply, erect and commission electrical plant and controls in connection with these developments.

LEICESTER CITY COUNCIL has awarded two contracts for sewage pumping plant for the Wanlip sewage disposal works scheme. A contract with Gwynnes Pumps Ltd. amounts to £18,500, and covers two 14in centrifugal pumps, motors pipes and valves, and four 8in pumps. A contract with W. H. Allen Sons and Co. Ltd. amounts to £7,400 and is for two 22in to 24in mixed-flow pumps and motors.

ELLIOTT BROTHERS (LONDON) LTD., a member of the Elliott-Automation Group, has received a £100,000 order from the Home Office for u.h.f. radio link terminals for a new Civil Defence network. This is believed to be the largest single order for this type of equipment ever placed in the United Kingdom. The equipment, which has been developed by the Telecommunications Division of Elliott Brothers (London) Ltd., is a new high-performance 10W u.h.f., f.m. radio link for use in the 460 Mc/s band.

TELECOMMUNICATIONS LTD., one of the Pye Group of Companies, has received an order from the Irish Department of Posts and Telegraphs for re-equipping the marine radio stations at Malin Head in the north, and Valentia in the south-west extremity of Ireland. The equipment ordered consists of a number of Pye 1kW m.f. transmitters equipped for three-channel operation and remote control. Malin Head was one of the eight coastal radio stations taken over by the British Post Office in 1909 to form the nucleus of a ship-shore service. This station and Valentia continue to form part of the coast station radiotelephony and radiotelegraphy services.

ELLIOTT-AUTOMATION LTD. has received an order from the Post Office for a National-Elliott 803 electronic digital computer for use at the G.P.O. satellite system radio station on the Lizard, Cornwall, in connection with transatlantic tests of communication satellites next year. The computer will be used to convert predicted orbital information derived from the "Minitrack" world-wide network of tracking stations into steering instructions on punched tape for controlling the 85ft diameter paraboloid steerable aerial at the Post Office radio station. At the appropriate time, the steering instructions on the punched tape will be fed into the electronic controlling equipment of the aerial which will then be pointed in the direction of the satellite as it appears above the horizon. Throughout the transit of the satellite, the aerial will continue to track it with a precision of the order of one-tenth of a degree.

THE GENERAL ELECTRIC COMPANY LTD. is to provide radio equipment for two s.h.f. radio-relay systems for the Australian Post Office, one between Sydney and Orange and the other between Brisbane and Mount Matheson. The Sydney-Orange link will be equipped to provide a both-way telephony system and a one-way television link. One channel in each direction will be used as a standby (protection) channel and will be switched into service should a working channel fail or become degraded. The Brisbane-Mount Matheson system will provide a duplicate (main and standby) one-way television link. Each radio frequency channel will operate in the 6000 Mc/s band and be capable of carrying 960 speech channels or a television programme. Equipment will be supplied for five repeater stations, two between Brisbane and Mount Matheson, and three between Sydney and Orange. The apparatus will be manufactured at the company's telephone works in Coventry.

Death

WE record with regret the death of Mr. Stanley S. Dawes, M.I.Mech.E., F.I.M.I., F.C.C.S., President Emeritus, The Institute of the Motor Industry. Mr. Dawes died on Sunday, December 17, at the age of seventy-one. He was President of the Institute for thirteen years, and in 1959 the Council of the Institute conferred the title of President Emeritus upon him in recognition of the services he had rendered to the Institute and its activities in the sphere of education within the motor industry.

CONTINENTAL AFFAIRS

by Our Continental Editor

Metre Interference Comparator

By means of light sources giving specially well-defined spectral lines it is possible to realise a continuous light-wave scale 800mm long representing over 2,000,000 divisions with an accuracy at any point of 0·01 micron. End gauges up to 1m in length may be measured absolutely or compared using the Kösters-Zeiss metre interference comparator. Three of these instruments have been built to date, of which the third was acquired a few months ago by the N.P.L. and has now been taken into full use.

THE first comparison of the metre standard with the wavelength of light was carried out by Michelson and Benoît at the International Bureau of Weights and Measures at Sèvres in 1892-93. These measurements were repeated in 1905-6 by Fabry and Perot using improved apparatus. Their result was adopted in 1907 for defining the International Angström Unit, the basic spectroscopic unit of length, in terms of the wavelength of the cadmium red line, in such a way as to make the Angström nominally equal to 10^{-10}m.

Interference measurements of length depend on the fact that two trains of lightwaves reinforce each other if in phase, and weaken or extinguish each other if out of phase. For this effect to be observable, the two wavetrains must be as identical as possible in all respects except phase, and this is achieved by splitting the light obtained from a single source. The two partial beams are reflected back on themselves by mirror surfaces and recombined, in which case, if the light is monochromatic, interference fringes are seen marking contours between which the path difference is half a wavelength. With white light, zero path difference can be very accurately identified from the fact that its position is marked by a clear central fringe while on either side are seen coloured fringes which quickly become blurred.

If the interfering beams are slightly inclined in respect to each other, an optical wedge is formed showing an array of fringes parallel to the line of intersection of the two faces of the wedge. The number of fringes, counting from the apex as the origin to any particular fringe, is known as the order of interference of that fringe.

Although the cadmium red line is comparatively sharp, it shows a definite broadening which makes it impossible to observe high orders of interference. This fact prevented Michelson and his successors from measuring the metre directly. Instead, a sub-standard had to be measured in terms of lightwaves and compared with another twice (or some simple multiple of) its length, and so on as far as the limit of fringe observation, after which the new auxiliary standard was placed, in effect, end to end several times until the metre length was reached. This procedure is cumbersome and not suited to routine work. Moreover, it is necessary to apply a correction so as to reduce the result to standard atmospheric conditions, or to vacuum.

These drawbacks are absent from the metre interference comparator invented by Kösters of the Physikalisch-Technische Reichsanstalt (P.T.R.) and now commercially produced by Carl Zeiss. The prototype instrument, which was completed in 1927, has since been redesigned by Dr. Engelhard of the Physikalisch-Technische Bundesanstalt, Brunswick, the successor to the P.T.R. Two models have been completed by Carl Zeiss, Oberkochen ; the first is in operation at the P.T.B., and the second was supplied a few months ago to the N.P.L., Teddington.

Fig. 1 shows the instrument diagrammatically. Its principal component is the interference double prism *A*. This has an equilateral cross-section and is set up with one face at right angles to the axis of the instrument, the other two being at 30 deg. The prism consists of two halves, the division being along the plane of symmetry in the direction of the axis of the instrument, and the interface is semi-silvered.

The interferometer is housed in a thick-walled aluminium case, which is water-jacketed, well insulated on the outside and provided with an airtight lid. In our illustration, it is shown set up for comparing two end gauges *BC* and *DE*, the gauges carrying wrung-on reference flats at *C* and *E*. For absolute measurements, one of the gauges would be replaced by a flat. In addition, there are seen two flat mirrors *F* and *G* which reflect back the light passing through 1m-long vacuum cells *H* and *K*, and compensating airfilled cells *J* and *L* incorporating the same glass covers.

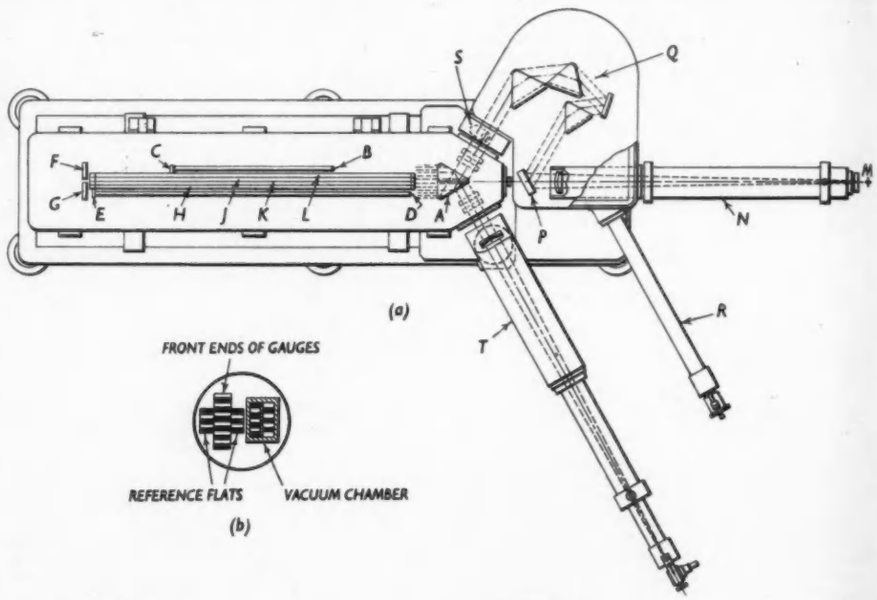
Light from a source at *M* falls on the slit of the collimating telescope *N*, and by way of an adjustable flat mirror *P*, reaches a set of dispersion prisms *Q* which are controlled by an adjustment *R* so that any particular spectral line can be selected ; it is also possible to introduce white light at *S*.

The light from the monochromator falls on the interference prism at right angles to one of the inclined faces and finally emerges at right angles to the other face, the beam being viewed by means of a telescope *T* fitted with a small aperture.

The geometry of prism *A* is such that light entering in the way described is divided at the interface into two partial beams which after internal reflection leave in a direction parallel to the axis, one beam emerging from each of the halves. They are reflected back by the front ends of the gauges, the reference flats, and the mirrors, and recombine at the prism interface where they interfere. The whole of the interference path is thus contained within the instrument so that the windows of the case do not need to be of very high quality.

Optical conditions are such that one half of the field is mirrored on the other, and optical wedges are formed between the two front faces of the gauges and between the two reference flats (left hand half of Fig. 1(*b*)), as well as between mirrors *F* and *G* (right hand half of Fig. 1(*b*)), by appropriate design of prism *A*, the adjustment of which is controlled by means of oil-filled bellows operated from the control desk.

The normal material of gauges is steel, which has a coefficient of expansion of the order of 11×10^{-6} per deg. Cent., so that care must be taken to achieve a completely uniform and controlled temperature. The case, which is maintained at constant temperature by the thermostatically controlled water-jacket, is fitted with a platinum resistance thermometer forming one arm of a Smith bridge, allowing temperatures to be measured to 0·001 deg. Cent. Near the resistance thermometer are the reference junctions of thermocouples, two of which are clipped on to



A—Interference prism.
BC, *DE*—End gauges.
B, *D*—Front ends.
C, *E*—Reference flats.
F, *G*—Mirrors backing vacuum chambers *H*, *J* and compensating chambers *K*, *L*.
M—Lamp.
N—Collimator.
P—Adjustable mirror.
Q—Dispersion prisms.
R—Prism control.
S—White light adjustment.
T—Telescope.

Fig. 1—(*a*) Diagram of metre interference comparator. (*b*) Field of view of telescope

each of the end gauges, and give their temperature to 0.01 deg. Cent. or better, which represents a possible error of $\pm 0{\cdot}1$ micron or less per metre.

Measurements are obtained directly as if the gauges had been placed in a vacuum. To do so in fact would cause uncontrolled change of size due to decompression of the gauge material. The method is as follows : the thickness of an optical wedge is $z\lambda/2$ where z=order of fringes, λ=wavelength. Let suffix o denote vacuum conditions, then for the vacuum and compensating cells, $z\lambda/2=z_o\lambda_o/2$ which(since $n=\lambda_o/\lambda$=refractive index of air against vacuum) reduces to $z=nz_o$.

Hence the difference in the order of the fringes seen in the right-hand half of Fig. 1(*b*), which is $z-z_o$, equals $z_o\,(n-1)$. Since $n=1{\cdot}000274$ for medium wavelengths, the difference $z-z_o$ is a comparatively small number of a few hundred to one-thousand-odd fringes, in spite of the large value of z (about 3,000,000 per metre). The value of $z-z_o$ is the correction required for the atmosphere, for a gauge 1m long ; for other lengths a proportionate value must be taken.

By closing the lid, the interferometer is made completely airtight, so that refraction, which is strictly proportional to density, is unchanged by small variations in temperature which leave the volume of the case practically constant. Provision is made for drying the air enclosed in the interferometer chamber. A correction for variations in displacement with different gauges is applied by removing or adding small steel blocks calibrated in cubic centimetres.

The amount of air, and hence the refractive index, may be varied by having the instrument connected to a cylinder and piston equipped with a scale. With the help of this arrangement, readings are carried out in the following manner.

From measurements of room temperature and barometric pressure of ordinary accuracy, the approximate number of vacuum fringes for a certain spectral line is calculated and the piston scale set to this value. The previously open system is now sealed by closing a cock, and by aligning the fringes seen over the vacuum and compensating chambers, the difference in orders due to vacuum is made equal to a whole number of fringes. The setting is checked by changing to other wavelengths, and noting whether on realignment of the fringes the piston scale readings are those marked for the wavelengths employed.

By means of the piston, the wavelength is now adjusted so as to make the order of the difference in length between the two gauges a whole number. The corresponding fringe difference between the vacuum chambers and compensating chambers is observed on the piston scale. In general, there will be a fractional difference which is measured. The result, multiplied by the approximate value of the difference between the gauges and subtracted from unity, gives the fraction of a half-wavelength *in vacuo* by which the required difference between the gauges exceeds a whole number of half-wavelengths. What that number is, is then found from tables, using the observed vacuum fractions for several wavelengths, and the approximate value of the difference.

Our second illustration shows the instrument in the laboratory. From right to left are seen the housing of the krypton lamp, a cadmium lamp, and on the floor, the instrument thermostat, and the control unit and vacuum pump required for the krypton lamp. In the centre are the collimator and monochromator, while the interferometer itself is on the left, with the control unit in front of the observer. It should be noted that the instrument stands on an ordinary floor. Since the interference paths are parallel and close together, any vibration affects both paths equally.

A krypton lamp is used for precision readings of long gauges because of the very sharp lines which are obtained. The main cause of line broadening is the Doppler effect due to thermal agitation of the radiating atoms. This is considerable in the case of the cadmium lamp since it operates at about 600 deg. K. In principle the best results are obtainable with a single heavy isotope of even mass number radiating at the lowest possible temperature. Lamps filled with mercury 198, artificially made from gold by neutron bombardment, and krypton 84 and 86, obtained from the natural mixture of isotopes by a thermal diffusion process, have been developed since the war, and it should be noted that the new definition of the metre adopted last October by the General Conference on Weights and Measures is based on the orange line of krypton 86.

The krypton lamp is a hot cathode discharge tube surrounded by a Dewar flask, filled with liquid air, situated inside an airtight envelope. By evacuating this envelope and thereby evaporating some of the liquid air, the temperature is lowered to the triple point of nitrogen (63 deg. K). The sharpness of the krypton lines is such that light scales of 800mm length can be realised, having over 2,000,000 division lines with an uncertainty of no more than $\pm 0{\cdot}01$ micron on the metre length (one part in 10^8) at any point. Gauges 1m long are calibrated in terms of a 500mm standard which in turn is measured absolutely.

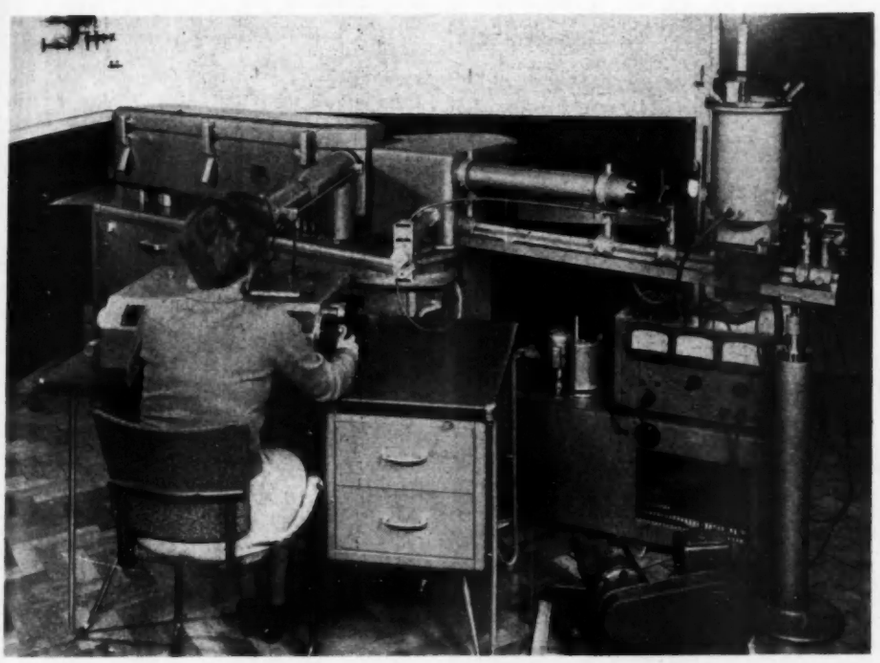


Fig. 2—Metre interference comparator at N.P.L. : (right to left) cadmium lamp housing, collimator monochrometer and interferometer. The control unit (in front of the observer) contains the cylinder and pistons for adjusting air density inside the instrument

Superfinishing Machine

We have received details of the Model "KW.3" crankshaft superfinishing machine made by Maschinenfabrik Ernst Thielenhaus, Wuppertal-Barmen, and now available in this country from the sole agent, Dorman Machinery Sales Ltd., Woodside Hill, Chalfont St. Peter, Bucks. This machine is supplied in three sizes having centres of 40in, 60in and 80in respectively. It is designed with tool carriers for the crankpin and journal bearings so that they can be superfinished simultaneously at the same setting.

The tool carriers for the crankpins are guided by the work itself. They have an articulated movement and are balanced in such a way that the contact pressure of the superfinishing stones can be individually adjusted. Changeover from one crankshaft to another having different crankpin dimensions is facilitated by setting the stones on the vertical bed of the machine. The tool carriers for the journal bearings are set on the horizontal bed of the machine and, like the crankpin tool carriers, can be independently adjusted for pressure and centre distances. An oscillatory movement which is infinitely variable from 0 to 800 oscillations per minute is provided by the headstock. The automatic cycle includes speed changes controlled by electrical timers.

All the hydraulic equipment and also the pump and tank for the lubricating oil, which is circulated through a fine filter, are housed in the fabricated bed. It is claimed that the average time for producing a finish of about 5 micro-inch on a six-cylinder crankshaft having six crankpins and up to seven journal bearings is two to three minutes. Finer surface finishes are readily obtained, if required, by continuing the superfinishing for a longer time. Larger machines can be supplied.

[Reply Card No. 1536]

Russian Oil Export

Although according to some authorities there is a potential world surplus of oil, the U.S.S.R., which has just overtaken Venezuela as the second largest oil-producing country in the world, is aiming to double her oil output in the course of the current seven-year plan (1959–65) to reach a figure of 230 million tons per annum, roughly equivalent to the entire production of the Middle East in 1959.

Even after allowing for a considerable increase in Russia's own requirements, such a level of output makes it appear inevitable that much more oil will be available for export, a conclusion which is reinforced by the fact that at the present time the U.S.S.R. is also engaged in the construction of pipelines and tankers.

Proven reserves in the U.S.S.R. are at present estimated to be roughly equivalent to those of the U.S.A.—a country which last year supplied two-and-a-half times as much oil. Production is now climbing rapidly ; since 1950 it has been quadrupled.

As a result, during the past few years Russia has found herself in the long unfamiliar position of having surplus oil available for export—not only to other countries in the Soviet bloc, but also to the free world outside. In 1959 her exports reached a record level, Western Europe being the main recipient with about three-quarters of the 22,000,000 tons which were marketed outside the Soviet bloc. The importance of these figures is more fully appreciated when it is recalled that in 1957 Western Europe took no Soviet oil at all—but last year derived from that source some 8 per cent of its appreciably higher requirements.

Industrial Aptitude Testing Centre

A *Centre Psychotechnique* for the testing of industrial aptitudes is to be opened by the Association des Industriels de Belgique (A.I.B.), 27–29, Avenue André Drouart, Auderghem-Bruxelles 16. From the beginning of the new year the centre will be able to undertake the testing of drivers of all classes of vehicles and mobile equipment, including lorries, tractors, fork-lift trucks, locomotives, cranes, &c. Tests will be of a kind already stipulated by insurance companies in France, and will include physiological and psychological aptitude tests as well as intelligence tests.

THE AMERICAN SCENE

By Our American Editor

National Metal Congress and Exposition

No. 1

THE Forty-third National Metal Congress and Exposition was held in Detroit, Michigan, from October 23 to 27. As in previous years, it was sponsored by the American Society for Metals, the Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers, and the Society for Non-Destructive Testing. About 400 companies engaged in either the production, treatment or fabrication of metals gave displays and demonstrations of their products or services at the Cobo Hall. Over the years, the Metal Show has continued to become ever broader in its coverage of the metals and metal working field, and gone are the days when it was concerned mainly with the heat-treatment of steels. This year there was again a strong accent on the fabrication and application of some of the more recently developed metals, such as beryllium, molybdenum, zirconium, columbium and tantalum. Among the trends to be noticed at the Metal Show were an increasing number of powder metallurgical products and processes ; greater uses of ultrasonic techniques in the fields of non-destructive testing, metal cleaning and metal joining ; an accent on "automation" applied to a variety of metal processing plant ; a number of electron beam plant uses ; and a growing popularity of vacuum melting furnaces and other vacuum processing equipment.

It is of particular interest to note that a large contingent of members and guests of the Iron and Steel Institute arrived at the Congress on October 25, as part of the special meeting being held in the United States and Canada. Members attended various technical meetings of the American Society for Metals and of the Metallurgical Society and visited the Metals Exposition in the Cobo Hall. While in Detroit, members also visited the hot strip mill of the Great Lakes Steel Corporation, at Ecorse, Michigan. Finally, members and their ladies attended the A.S.M. annual banquet held in the Statler-Hilton Hotel on October 26. On this occasion, the A.S.M. Gold Medal was awarded to Professor Cyril S. Smith, of the Massachusetts Institute of Technology, and Sir Charles Goodeve, President of the Iron and Steel Institute, was admitted to Distinguished Life Membership in the American Society for Metals. (See also page 910 *ante*).

International Nickel Company

The International Nickel Company, of New York, announced the development of a 25 per cent nickel mar-ageing steel, which attains high strength by heat treatment without quenching. This steel is partially austenitic as annealed and is soft and readily workable in that condition. Simple heat treatment or cold work and ageing produces a high level of strength combined with good notch strength. The alloy can be rough machined in the annealed condition or prior to final ageing. After ageing, light finish machining is feasible.

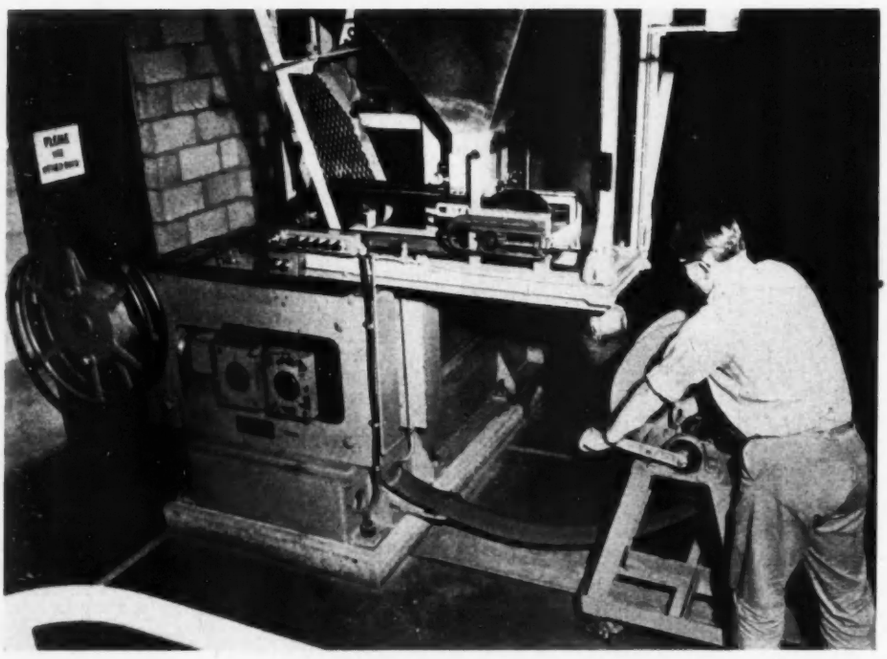


Fig. 1—Cold compacting of pure cobalt powder in a horizontal Loma rolling mill, forming "green" strip at Sherritt Gordon Mines

The composition range for the steel, at the present state of development, is as follows :

Nickel	25·0–26·0 per cent
Titanium	1·3–1·6 per cent
Aluminium	0·15–0·35 per cent
Columbium	0·3–0·6 per cent
Carbon	0·03 maximum
Manganese	0·15 maximum
Silicon	0·15 maximum
Sulphur	0·01 maximum
Phosphorus	0·01 maximum
Boron	0·003 added
Zirconium	0·02 added
Calcium	0·05 added

Pilot production heats have either been vacuum induction melted or air melted and then consumable-electrode remelted in vacuum. The workability, both hot and cold, of the steel is very good. The hot working recommendations are as follows :

Forging range	2250–1850 deg. Fah.
Intermediate homogenisation	2–3 hours at 2300 deg. Fah.
Hot rolling range	1900–1500 deg. Fah.
Finishing temperature	1500 deg. Fah.

To obtain optimum results, the 1500 deg. Fah. finishing temperature should be closely adhered to and the rolling should be such that the material will have undergone about 25 per cent reduction near that temperature. It is recommended that the steel be annealed after hot work as follows :

Heat at any convenient rate to 1500 deg. Fah ±25 deg. (protective atmosphere not required).

Soak about one hour per inch of thickness.

Air cool.

The tensile properties and hardness in the annealed condition are as tabulated below :

0·2 per cent offset yield strength	40,000 lb per square inch
Ultimate strength	132,000 lb per square inch
Elongation	30 per cent
Reduction of area	72 per cent
Hardness	10–15 Rockwell "C"

A simple heat treatment to develop full properties is as follows :

Anneal at 1500 deg. Fah. as described above.

Heat to 1300 deg. Fah., soak four hours, air cool. This results in the precipitation of Ti and Ni from solid solution with a consequent elevation of Ms to +160 deg. Fah. or higher.

Refrigerate at −100 deg. Fah. for several hours. This treatment may be omitted in those cases where the titanium content is near the upper side of the range. It is definitely recommended for low-titanium heats or where properties towards the high side of the range are desired.

Age at 800–900 deg. Fah. for one to four hours, air cool. Ageing toward the upper side of this range need not be extended beyond one hour and care should be taken not to exceed 900 deg. Fah. to avoid reversion to austenite.

The alternate procedure for attaining full properties involves cold work, after annealing, followed by ageing. This treatment is as follows :

Anneal at 1500 deg. Fah., air cool.

Cold work (25 per cent reduction, or more).

Refrigerate at −100 deg. Fah.

Age at 800–900 deg. Fah., one to four hours, air cool.

By either of the processing cycles, the properties for the specified composition, after final ageing, will be within the following range, with the cold worked and aged material having values toward the high side of the range for each property listed :

0·2 per cent offset yield strength	240,000–270,000 lb per square inch
Ultimate strength	260,000–290,000 lb per square inch
Elongation in 1in	10–15 per cent
Reduction of area	40–60 per cent
Notch tensile strength	280,000–360,000 lb per square inch

Sound welds can be made by coated electrode or by inert gas, consumable-electrode or tungsten arc techniques, using electrodes of approximately

the same composition as the base material. Welding may be accomplished without preheat on material fully hardened by heat treatment, but post-weld treatment involving both the 1300 deg. Fah. treatment and final ageing is required to restore the heat-affected zone of the parent plate to full properties. A property evaluation of weldments made of the 25 per cent nickel mar-ageing steel is in progress at this time, and specific data are not yet available.

Sherritt Gordon Mines

Commercially available for the first time, pure cobalt coiled strip with good ductility and workability was exhibited and is now being offered by Sherritt Gordon Mines Ltd., of Toronto, Ontario, in thicknesses ranging from 0·005in to 0·025in and in widths of ¼in to 6in. The strip will be supplied in production lots at prices favouring quantity orders.

Pure cobalt metal in strip form has not been commercially available because it was said to lack the ductility and workability essential in metal-working operations. Its important electrical and mechanical properties and corrosion resistance were utilised chiefly in alloying. The firm's new and more ductile cobalt strip preserves these properties and extends the application of cobalt to a much wider range of products. The improvement in properties is said to result from the purity of the product. Sherritt cobalt strip is rolled directly from the company's pure cobalt powder using a new powder rolling process which produces 99·9 per cent pure cobalt strip. The mechanical properties of the cobalt strip can be readily adjusted by proper heat treatment. For example, cobalt strip, cold rolled to a 25 per cent reduction, has a tensile strength of 165,000 lb per square inch, an elongation of 0·5 per cent and a Rockwell hardness (45T) of 85. In the annealed condition, this strip has a tensile strength of 115,000 lb per square inch, an elongation of 15 per cent and a Rockwell hardness (45T) of 68.

The difference in the strip properties depends on the crystal structure. There are two crystal forms of cobalt metal : close-packed hexagonal at temperatures up to 785 deg. Fah. ; and face-centered cubic from this temperature up to the melting point. However, on cooling after heat treatment above 785 deg. Fah., the transformation to the low temperature phase is sluggish, retarding the formation of a completely hexagonal structure at room temperature. The result is a mixture of retained face-centered cubic and newly formed hexagonal metal. The type of heat treatment and the eventual proportion of the two crystal phases present after cooling have an effect on the ductility of the cobalt. With the improvement in ductility, cobalt strip becomes an important design material for applications where corrosion resistance and high strength at high temperatures are essential. Cobalt is twice as strong as nickel, retains this strength to higher temperatures, and has similar corrosion resistance. Cobalt also has excellent magnetic properties which are retained to a higher Curie point than nickel. One promising application for cobalt strip is magnetic tape for computers.

Sherritt cobalt strip is rolled directly from pure cobalt powder in a three-step process. First, the cobalt powder is cold compacted in a Loma horizontal rolling mill to form " green " strip 6in wide, about 0·060in and 70 to 80 per cent dense. Upon emerging from the mill, the strip is wound into coils, and, next, the " green " strip is sintered in a hydrogen atmosphere. Sintering bonds the cobalt particles together and causes an increase in strength and a slight increase in density. After sintering, the strip is ready for hot rolling. Strip feeds directly from the sintering furnace to a vertical hot rolling mill where the thickness is reduced by about 30 per cent.

Hot rolling eliminates the porosity and in this fully dense form the strip is perfectly satisfactory for metal-working operations. Subsequent processing is done by any of the metal-forming procedures suitable for metals with these properties. The typical chemical analysis of the cobalt strip is as follows :

Cobalt	99·9 per cent
Nickel	0·10 per cent
Copper	0·005 per cent
Iron	0·018 per cent
Sulphur	0·004 per cent
Carbon	0·04 per cent

Beryllium Corporation

The Beryllium Corporation, of Reading, Pennsylvania, announced at the Metal Show that beryllium nickel alloy strip, or narrow width sheet, will be made available for the first time in various sizes and tempers. The new alloy is comparable in appearance to pure nickel or high nickel alloys with similar corrosion resistance properties. It offers extremely high strength and hardness with tensile strength up to 260,000 lb per square inch and Rockwell hardness to C-53, depending upon heat treatment.

Prior to the announcement of the availability of beryllium nickel in wrought form, the alloy could only be obtained in ingots for use by foundries in casting parts for critical applications. With the introduction of beryllium nickel strip the material can now be considered for use as heat resistant springs, diaphragms, and other highly stressed parts where hardness, corrosion and oxidation-resistance are required. Typical mechanical properties of beryllium nickel strip are :

Temper	Tensile strength lb per square inch	Yield strength 0·2 per cent offset, lb per square inch	Elongation, per cent	Modulus of elasticity ×10⁶ lb per square inch	Hardness (Rockwell)
A	91,000	37,000	40	26	B-57
AT	190,000	150,000	6	28	C-47
H	150,000	142,000	3	28	C-32
HT	260,000	233,000	3	30	C-53

The firm also announced that a beryllium copper alloy, referred to as "160", has been selected as the material for the casings and couplings that will be used in the rigid repeaters of the new underwater telephone cable system. The alloy was jointly developed by the Beryllium Corporation and the Bell Telephone Laboratories. The casings for the repeater measure 30in in length and 13in in diameter and are finish machined to close tolerances. The production of the casings starts with a 6ft by 23in diameter billet that is then processed by sawing, extruding, machining, and surface grinding to a final product of close tolerances.

Beryllium copper couplings are utilised at both ends of the repeater unit to provide a flexible connection of the single co-axial telephone cable to the repeater housing, reducing possible stresses that might be encountered during the cable laying operation and due to variations of the ocean floor when the cable is in position. Beryllium copper alloy was selected over other materials due to the nature of the application and the requirements for reliability and performance. The alloy is highly resistant to salt water corrosion with unusual strength and hardness characteristics which enable it to withstand continuous pressures of 12,000 lb per square inch despite a relatively light wall thickness.

The new undersea cable system, embodying the latest developments in telephone technology, is now scheduled for installation during 1962 to keep pace with the rising volume of U.S. overseas telephone calls which reached almost 4,000,000 last year. The first installation of the new cable will link the United States and Jamaica, and in 1963 the first direct cable between the United States and Great Britain will be completed. New cables are planned to link the United States with Hawaii and Hawaii with Japan by 1964.

Wilbur B. Driver Company

An important advance in nickel-chromium heating element materials was demonstrated by the Wilbur B. Driver Company, of Newark, New Jersey. This firm's " Tophet 30 " is an entirely new nickel-chromium resistance alloy designed for use over the entire range of operating temperatures up to 2300 deg. Fah. with the ability to withstand exposure at elevated temperatures in air or protective atmospheres, under cyclic or steady state conditions, for longer periods of time. The new material is essentially a 70 per cent nickel, 30 per cent chromium alloy.

A nickel-chromium alloy with more than 25 per cent chromium content represents a new departure in that it was formerly impossible to consistently work such an alloy. However, the company's research department has been able to develop an alloy containing 30 per cent chromium which is worked as easily as the lower chromium content alloys by the use of improved melting and hot working techniques.

The life of an alloy is defined as the ability of that alloy to withstand an exposure at elevated temperatures under cyclic conditions, for prolonged periods of time. " Tophet 30 " was cyclically life tested in air over a temperature range from 2100 deg. Fah. to 2400 deg. Fah. The results were compared to those of previous tests made on conventional 80/20 nickel-chromium alloys. They show that the new alloy has a total mean life-to-burnout from 62 to 100 per cent greater at all of the test temperatures. While the mean life of " Tophet 30 " offers a substantial gain, the figures for maximum life are even more striking. Individual life tests in air as high as 780 hours at 2100 deg. Fah., 490 hours at 2150 deg. Fah., and 310 hours at 2200 deg. Fah. have been recorded.

Numerous furnace tests have been run in a rich unpurified exothermic gas (" Green Rot " atmosphere) in accordance with A.S.T.M. specification B–181–50. No evidence of " Green Rot " attack has ever been detected, even in tests conducted for 1200 hours—four times as long as specified in B–181–50. Tests for 1000 hours in wet cracked ammonia likewise showed no attack. In cyclic life tests in " Green Rot " atmosphere, the new alloy has run for 1059 hours to burnout in the constant temperature cyclic test at 2150 deg. Fah.

Superior Tube Company

An interesting development on display at Detroit was integrally finned tubing made by The Superior Tube Company of Norristown, Pennsylvania. Both straight and spiral finned tubing are now being produced by drawing the fin as an integral part of the tube. This integral fin is presently available only on the outside surface. This unique one-piece construction method for making finned tubing offers several advantages over the more conventional methods of welding or brazing a fin to the outside surface of a tube. The advantages of integrally finned tubing are as follows : (1) it is stronger ; (2) the fin has exactly the same chemical composition as the rest of the tube ; (3) the one-piece construction provides constant physical and mechanical properties throughout ; and (4) since there are no voids between the fin and the tube wall, the danger of corrosion in this area is eliminated.

Straight finned tubing can be produced with as many as eight fins spaced around the circumference of the tube and running the full length of the tube. The size limits on the fin are 0·010in to 0·030in in fin width and 0·010in to 0·100in in height over the entire size range. The placement of the fins on the outside surface of the tube can be in accordance with any specification. The maximum length available for straight finned tubing is 24ft.

Integral finned tubing can also be produced with the fin spiralling around the circumference of the outside surface of the tube. One 360 deg. spiral finned twist can be produced and repeated at intervals ranging from 5in up to 12in. As with straight finned tubing, a maximum of eight spiral fins can be produced on a single length of tubing. Spiral finned tubing is limited to lengths of 10ft.

Finned tubing of both types can be produced in a size range from ¼in to ½in o.d. with all thicknesses from 0·020in to 0·060in. Two outstanding applications for integral finned tubing are nuclear reactor fuel element cladding and heat exchanger tubing. The one-piece construction affords exceptionally close tolerance control which is of particular importance in fuel element cladding tubing. The spacing between the tubes in the fuel element tubing bundle is a critical factor and to ensure proper nesting the overall dimension must be extremely uniform

THE AMERICAN SCENE *(Continued)*

on each length of tubing. The extended surface on finned tubing provides better heat transfer and rigidity than that available with standard tubing for nuclear heat exchanger applications.

Both straight and spiral finned tubing is available from the firm in the 300 and 400 series stainless steels, nickel and nickel alloys, including Inconel and Monel. For fuel element cladding, integrally finned tubing is available in zirconium and Zircaloy and columbium and columbium alloy. Straight finned tubing is available in the three standard tubing tempers of annealed, half hard and full hard. Spiral finned tubing can only be supplied in the annealed conditions or in the as-twisted temper.

Linde Company

Plasma arc weld surfacing, a new precision method for depositing fully-fused overlays of wear- and corrosion-resistant alloys, was demonstrated at the Metal Show by the Linde Company, a Division of the Union Carbide Corporation, New York. The new process is claimed to be the first one capable of depositing a very-thin fused coating with controlled dilution at high speeds. The overlay metal or alloy is fed as a powder into the " Plasmarc " torch. Intense heat is created by a constricted plasma arc produced within the torch and transferred from the torch to the work. Argon gas is used to form the plasma and also shields the surfaced area from atmospheric contamination.

The general plasma arc processes can use almost any gas to form the plasma. Non-oxidising gas is generally used in metalworking torches. The rate at which the gas transfers heat is more important than the temperature which the gas reaches. The higher the thermal conductivity of the gas, the more heat will be transferred. Argon and hydrogen produce arcs of similar temperature range, but hydrogen transfers more heat, because of its higher thermal conductivity.

The plasma arc combines the directional stability of a combustion flame with the high temperature of an electric arc. There are three ways to control the temperature and length of the plasma arc : one can vary the current, vary the flow or composition of the gas, or modify the orifice size. A plasma arc runs from 6000 deg. Fah. to 100,000 deg. Fah. The hottest combustion flame now available economically is the oxy-acetylene flame with a 6000 deg. Fah. maximum. One can get plasma arc velocities of thousands of feet per second and flames many feet in length in a power range of a few watts to many megawatts.

There are two types of constricted plasma-arc torches, transferred-arc and non-transferred-arc, differing physically in the electrical connections. In the transferred-arc torch, both the arc and the stream leave the nozzle. The work piece is an electrode in the circuit. In the non-transferred-arc torch, the nozzle itself is an electrode. The arc ends at the nozzle ; only the hot discharged stream reaches the work piece. The transferred-arc torch can transfer more heat and do it more efficiently than the non-transferred-arc. It is used mainly for welding and cutting, which call for melting the work piece, and for surfacing applications which require fusing the surfacing material to the base metal.

The non-transferred-arc torch can concentrate its heat inside the torch. Its greatest use is for plating. The plating material is heated to a plastic or molten state inside the torch and blasted on to the work piece. The non-transferred-arc torch has a variety of other uses : to melt ceramic materials and simulate atmospheric re-entry conditions ; in studies of ion-propulsion engines, high-temperature chemical reactions and refractory crystal growth, as a source of high-intensity light ; and as a heat source for extractive metallurgy and high-temperature machining.

The non-transferred-arc torch is important in applying platings of refractory materials, particularly to parts for missiles and rockets. Metallic and non-metallic materials and even certain reinforced plastics can be coated. The coating material can be almost any inorganic solid that can be melted without decomposing. Coatings can be made any thickness, by depositing layer on layer, and there is no sacrifice for mechanical strength. Coatings successfully used so far include tungsten, tantalum, molybdenum, nickel, platinum, aluminium, alumina, and zirconia. Plasma-plating coats tungsten on graphite for rocket nozzles. Plasma-plating also serves in the fabrication of tungsten parts by applying successive coatings to a mandrel, which is later removed. The tungsten parts and coatings, as-coated, have densities up to 90 per cent of theoretical, a modulus of rupture of 50,000 lb per square inch, and a Young's modulus of 24×10^6 lb per square inch. All of these can be improved substantially by heat treatment. A finer surface finish may be obtained by standard equipment and methods of grinding, lapping, or polishing the coatings.

The " Plasmarc " cutting process was originally introduced to cut aluminium up to 1¼in thick and was soon used also to cut magnesium, stainless steel, copper and nickel. Recent research has made it possible to cut aluminium up to 5in thick and stainless steel and other metals up to 4in thick. Plasma cutting can reach speeds of over 1000in per minute but most metal cutting is done between 10in and 300in per minute.

The new " Plasmarc " weld surfacing technique is of particular interest due to its ability to deposit a very thin fused coating with controlled dilution at high speeds. The deposit is a true weld, fused to the work piece. It resists impact and high stresses and is free of porosity. The operator can control the dilution of the deposit in a range of from 5 to 50 per cent. " Plasmarc " surfacing can produce weld overlays 0·010in thick and greater from a variety of metal powders. By adjusting the powder formulations users have deposited successfully nickel, copper, and cobalt-base alloys, stainless steel materials containing chrome-carbide, and heterogeneous materials such as tungsten carbide particles in a steel base.

American Machine and Foundry Company

The initial public display of the friction welding machine developed by the American Machine and Foundry Company, Niles, Illinois, took place at the exhibition. The study of friction welding by the firm's research and development division proved that for many types of welds, this method is more efficient than conventional methods and requires less power. It was also found that the new method generally eliminated the need for fluxes and special atmospheres.

The firm's friction welding machines are now available to industry. The Model 15-4, illustrated on page 940, Dec. 1, 1961, has a weld capacity of 1¾ square inches and a maximum axial thrust of 20,000 lb. The model 75-A has a weld capacity of 10 square inches and a maximum axial thrust of 130,000 lb.

These machines can be programmed easily into a production line, and are ruggedly built for heavy-duty production service. With the proper cycle set into the machine, welds are readily reproducible ; highly skilled operators are not necessary. The cycle of the model 75-A includes automatic chucking and unchucking of the work pieces. Because all the heat is generated where it is needed—at the contacting surfaces—these machines are extremely efficient : power consumption is a fraction of that needed for flash, pressure, or induction welding.

Tension, flexure, impact, reverse bend, and other metallurgical tests show that friction-welded joints equal or exceed the performance o joints made by other processes. An important accomplishment of the friction welding process is the welding of dissimilar metals, such as copper to brass and brass to aluminium. In extremely difficult cases, a sound weld can often be made by welding a mutually compatible slug between the work pieces. Friction welding has made it possible to join some dissimilar metals directly that cannot be welded by any other method.

Because friction welding is so rapid, large heat-affected zones can be avoided. Also, because the heat generated by friction is self-limiting, excessive temperatures, which can be detrimental to the weld, are avoided. Friction welds, by their nature, are free of irregularities, such as those often caused by voids, slag, or other inclusions.

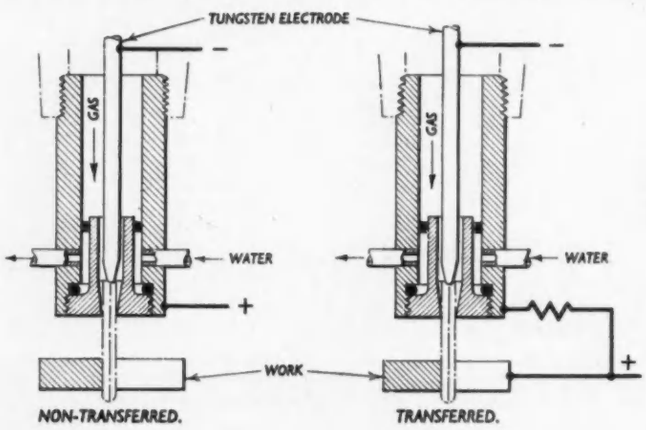


Fig. 2—Differences in electrical connections in non-transferred and transferred arc torches for the plasma arc process

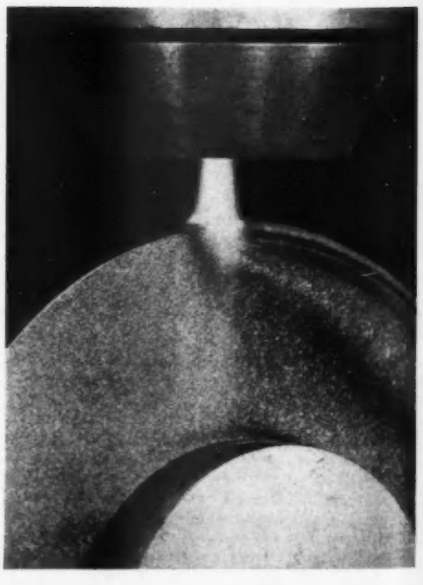


Fig. 3—Applying " Stellite 157-M " alloy deposit to the periphery of a 4in diameter disc by the " Plasmarc " weld surfacing process

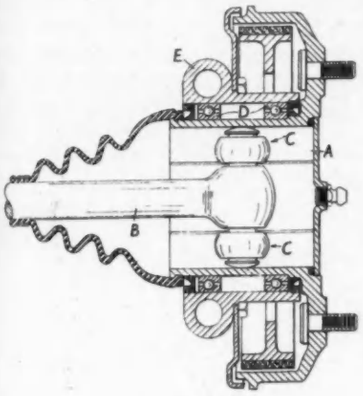
BRITISH PATENT SPECIFICATIONS

The dates printed are those of application and publication on completion. Copies of specifications may be obtained at the Patent Office Sales Branch, Southampton Buildings, Chancery Lane, W.C.2, 4s. 6d. each

MOTOR VEHICLES

883,616. July 7, 1959.—MOTOR VEHICLE TRANSMISSION SYSTEMS, Birfield Engineering Ltd., Stratford House, Stratford Place, London, W.1. (*Inventor : Raymond James Cooper.*)

The object of this invention is to provide an improved final drive arrangement for a motor vehicle with independently suspended driven wheels which will, in particular, enable half-shafts of longer length to be used for a given vehicle track and the unsprung weight of the vehicle to be reduced. The accompanying drawing illustrates one embodiment of the invention in the form of a complete wheel hub,



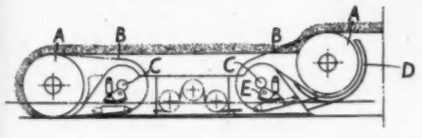
No. 833,616

brake and axle half-shaft assembly. A hollow cylindrical central hub portion providing a " pot joint " body member is formed integrally at its outer end with a brake drum and has in its two diametrically opposed bore longitudinally extending guideways *A* which form guide means of the joint. An axle half-shaft *B* projects into the hollow hub and at its outer end within the hub has pivots *C* which engage with the guideways. These pivot assemblies comprise a cross pin which carries part-spherical bearing races near its ends. These races enable the pivot to execute a rolling movement along the guideways to accommodate relative axial movement of the half-shaft and hub. The guideways have surface radii corresponding to those of the bearing races. The inner end of the hub is sealed by a flexible rubber boot which at its inner end is clamped around the half-shaft by a ring. The central hub portion is mounted on two spaced antifriction bearings *D* in a wheel hub structure which is provided with lugs *E* for mounting the assembly on the vehicle.—*December* 6, 1961.

MINING MACHINERY

883,602. September 20, 1960.—MINING MACHINE FOR CUTTING COAL, Mining Engineering Company Ltd., Meco Works, Worcester. (*Inventor: Thomas Campbell Paul.*)

The mining machine for cutting coal in accordance with this invention is illustrated diagrammatically in the accompanying drawing. The machine comprises



No. 883,602

an elongated frame adapted to be moved along a coal face by any convenient means. At each end of the machine there is a transverse shaft carrying a helical scroll *A* of greater diameter than the height of the frame, the edge of the scroll carrying teeth or picks to cut into the coal in front of the machine. The scroll shaft is driven by an exposed picked chain *B* on the face side of the machine from a cross shaft *C* in the frame. The scroll shaft which is overhung is mounted on the face side of the machine in a sub-frame which is angularly movable about the axis of *C* to adjust the position of the scroll relative to the floor. The adjustment of the sub-frame is effected by hydraulic rams. When the machine is in operation, whichever scroll is leading is set in the position shown on the left in the drawing, so that it cuts the coal between the floor and the level of the top of the scroll. The trailing scroll is adjusted to the position shown on the right and cuts the coal between the roof and the surface left by the leading scroll. The cutting circles of the scrolls overlap, and the setting of the trailing scroll is such that the total depth of coal cut is substantially equal to the depth of the seam. The picked chains on the face side trim the coal face and maintain a clearance for the movement of the machine. The coal cut by the scrolls is discharged on to a face conveyor parallel to the coal face. A curved trough *D* concentric with the scroll is mounted on the trailing unit to retain the cut coal as it is moved transversely towards the conveyor, this trough being transferred to the unit at the other end of the machine when movement is reversed at the end of the face. Shoes *E* adjustable by hydraulic rams may be mounted on the side of the machine next to the conveyor, to bear on the side frame and used to adjust the position of the machine.—*December* 6, 1961.

METALLURGY

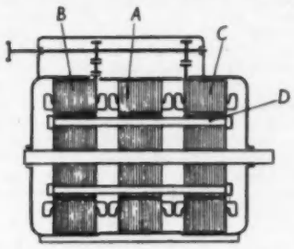
883,833. January 6, 1960.—PRODUCTION OF CAST IRON, The International Meehanite Metal Company Ltd., Meerion House, 4, Downside, Epsom, Surrey. (*Inventor : Edward William Harding.*)

This invention relates to a process for producing cast iron having the graphitic carbon in the nodular or spheroidal form. It is designed to provide a process for producing selected matrix structures in iron castings containing nodular or spheroidal graphite, to impart properties such as increased strength, ductility, impact strength and wear resistance. A further object is to reduce the annealing time required to decompose free carbides resulting from a nodularising treatment. It has been found that tellurium may be used with advantage in the production of nodular or spheroidal graphite cast iron by enabling matrix structures to be produced and accurately controlled in relation to the casting sections and to suit the service conditions. It has also been found that the structure of the cast iron produced can be controlled so that the combined carbon present in the finished casting is in an unstable form which can be readily broken down where required to perlite and/or ferrite by a suitable anneal, thus providing increased ductility in the metal with shorter annealing times than would otherwise be possible. The iron as melted is treated with tellurium and then with a nodularising graphitiser in such amounts that the tellurium addition increases the wedge value of the base metal to within the range of one-fifth to nine-tenths of the mean casting section. The term " mean casting section " as used means half the sum of the maximum and the minimum sections of the casting. Preferably the tellurium is added to the molten metal in the form of metallic tellurium or as an alloy of tellurium with iron or copper, prior to nodularising treatment and the amount used in processing is accurately controlled in relation to the section thickness of the casting, so as to develop a required structure prior to the nodularising treatment. The nodularising graphitiser is then added in a controlled amount, to produce in the final casting nodular or spheroidal graphite and a matrix structure giving the required mechanical properties and service performance. Preferably the nodularising graphitiser consists of magnesium-silicon or calcium-silicon or a mixture of the two added to the molten metal by surface or sub-surface treatment.—*December* 6, 1961.

ELECTRICAL ENGINEERING

883,925. November 11, 1959.—ADJUSTABLE-SPEED INDUCTION MOTOR, Zavody V. I. Lenina Plzen, Narodni Podnik, Plzen, Czechoslovakia.

This invention relates to an adjustable-speed squirrel-cage induction motor. The stator of an induction motor according to the invention is illustrated and includes a fixed part *B* and two rotatably mounted parts *A*, *C*, which are mechanically interconnected so that they can simultaneously be deflected from an initial position by the same angle, one of them turning in a clockwise direction and the other one in a counter-clockwise direction. The fixed part *B* and both rotatable parts *A* and *C* are fitted with independent single-phase windings energised from the one phase of the mains. The rotor *D* is common for both fixed and rotatable parts. It consists of insulated conductors, short-circuited by end rings or, alternatively a short-circuited wound rotor may be used. When the electrical axes of all parts *A*, *B*, *C* of the stator lie in one plane, the rotor does not revolve, since the resultant induction effect of all three alternating magnetic poles in the rotor is cancelled and the tangential component of the speed of magnetic field relatively to the standing rotor is reduced to zero. When the rotatable part *A* of the

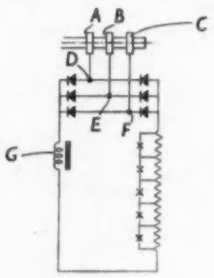


No. 883,925

stator is deflected by a certain angle in one direction, whilst the other rotatable part *C* is deflected by the same angle in opposite direction, the speed of the magnetic field acquires a tangential component, which is determined by the mains frequency, by the angle of deflection, and by the phase angle of the supply to each stator with respect to the fixed stator, i.e. 120 deg. for the three-phase machine described. This speed component causes the rotor to revolve, the direction depending on that in which rotatable parts *A*, *C*, of the stator have been deflected. If these are deflected in the reverse direction, the direction in which the rotor revolves is reversed, too. Under ideal no-load conditions the rotational speed of the rotor agrees with that of the tangential component of the magnetic field. When the rotor is loaded with a mechanical torque, a slip arises, the rotor is slowed down and active current is delivered from the mains to all three parts of the stator. Other features of the motor to which the invention relates are similar to those of an ordinary three-phase induction motor.—*December* 6, 1961.

883,852. July 24, 1958.—CONTROL OF INDUCTION MOTORS, Associated Electrical Industries Ltd., 33, Grosvenor Place, London, S.W.1. (*Inventor: Thomas Hayes Petch.*)

This invention relates to induction motors having rotor windings connected to external resistor sections which are switch-controlled to provide, through resistance change in the rotor circuit, a desired current and torque control, particularly during starting periods. It aims at an improved circuit which ensures that the



No. 883,852

current and torque changes are more gradual than with conventional motors of this kind. In the embodiment illustrated slip rings *A*, *B*, *C*, of a three-phase rotor winding (not shown) are connected each to a point *D*, *E*, *F*, between the inner terminals of an associated pair of rectifiers poled for full wave operation. The outer terminals at the left-hand side of the rectifier group are connected to an inductor *G* and the outer terminals at the right-hand side of the second rectifier group are connected to a series of resistor sections each of which is controlled in known manner by a short-circuiting switch. The other ends of the inductor *G* and resistor group are interconnected so that the resistor sections and inductor form a series circuit connected across all the full-wave rectifiers. The specification also describes a further embodiment in which separate resistances in each phase of the rotor can be individually controlled.—*December* 6, 1961.

British Standards Institution

All British Standard Specifications can be obtained from the Sales Department of the Institution at 2, Park Street, London, W.1.

MEASUREMENT OF NOISE EMITTED BY MOTOR VEHICLES

No. 3425 : 1961. Price 3s. This standard provides a uniform and repeatable method of determining objectively the noise of a moving motor vehicle, so that this can be compared with a pre-determined and arbitrarily set sound level value representing an acceptable standard of performance. The standard is based on and follows the recommendation for methods of measurement of noise emitted by vehicles now being drafted by the International Standards Organisation (I.S.O.). The method specified in the British Standard is based on an acceleration test at full throttle from a stated vehicle running condition in an acoustical environment which can only be obtained in an extensive open space. The test, while not necessarily measuring the highest noise of which the vehicle is capable, is nevertheless considered to give results adequately representative of the noise-producing potential under full throttle conditions. It is emphasised in the standard that the method specified only gives an objective measure of the noise emitted under the prescribed conditions of test and that subjective appraisals of noise such as loudness or annoyance are not simply or uniquely related to sound level meter readings.

CAST IRON SPIGOT AND SOCKET PIPES (VERTICALLY CAST) AND SPIGOT AND SOCKET FITTINGS PART 1 : PIPES

No. 78 : 1961. Price 5s. In revising this standard it was decided to divide it into two parts. Part 1, just published, deals with cast iron spigot and socket pipes vertically cast. Part 2, when published, will cover cast iron fittings for use with pipes manufactured in accordance with Part 1 and B.S.1211.

Some simplification has been achieved in the revision by eliminating two different external diameters on classes "A" and "B," and "C" and "D"; the testing procedure has been somewhat modified. The taking of test bars for tensile and transverse tests to represent the day's output has never been considered satisfactory by many users because the test pieces could not be identified with any particular pipes. Advantage is, therefore, taken of the hydraulic test applied at the works to prove the strength of the material of each individual pipe by subjecting it to a test pressure higher than that previously specified.

Certain diameters and lengths of pipe included in the 1939 edition of the specification have been omitted as they are no longer in common use. The diameters now specified have been divided into preferred and non-preferred sizes.

The specification gives information regarding quality of metal used in the casting of pipes, the mode of casting, the test to be applied and the coating normally used, together with tables giving weights and dimensions.

RED LEAD FOR PAINTS AND JOINTING COMPOUNDS

No. 217 : 1961. Price 5s. This is a revision of B.S.217. The revision has resulted mainly in the fixing of an upper limit for the content of ordinary red lead for paints, and the raising of the minimum content of the non-setting variety. The standard specifies materials, composition, non-setting properties, residue on sieve, oil absorption, value, colour, matter soluble in water, and matter volatile at 100 deg. Cent. Sampling and methods of testing are also described.

Forthcoming Engagements

Secretaries of Institutions, Societies, &c., desirous of having notices of meetings inserted in this column are requested to note that, in order to make sure of their insertion, the necessary information should reach this office not later than a fortnight before the meeting. In all cases the TIME *and* PLACE *at which the meeting is to be held should be clearly stated.*

ASSOCIATION OF SUPERVISING ELECTRICAL ENGINEERS

Mon., Jan. 1, 1962.—SOUTH WALES BRANCH : South Wales Institute of Engineers, Park Place, Cardiff, Films, 7.30 p.m.
Tues., Jan. 2, 1962.—SOUTH EAST LONDON BRANCH : Eltham Green School, Queenscroft Road, Eltham, London, S.E.9, Films, 7.45 p.m. ★ WEST LONDON BRANCH : White Hart, 49, King's Road, Chelsea, London, S.W.3, "Hospital Electrical Installations," R. H. Betteley, 7.45 p.m. ★ READING AND DISTRICTS BRANCH : Caversham Social Club, Caversham, Reading, "Photo-electric Cells," 7.30 p.m.
Wed., Jan. 3, 1962.—NORTH LONDON BRANCH : Wood Green Civic Centre, Wood Green, London, N.22, "The Railways and Industry," D. L. Barlow, 8 p.m. ★ MANCHESTER BRANCH : N.W. Electricity Board Service Centre Theatre, Town Hall Extension, St. Peter's Square, Manchester, 2, Lecturettes, 7.30 p.m. ★ PRESTON BRANCH : Farmer's Arms Hotel, Market Street, Preston, "The Rayon Industry and its Electrification," C. R. Seed, 7.30 p.m.
Thurs., Jan. 4, 1962.—BRIGHTON, HOVE AND DISTRICT BRANCH : Cricketers Hotel, Black Lion Street, Brighton, 1, "New Requirements for Lighting Commercial Buildings," J. E. Roper, 7.30 p.m.
Fri., Jan. 5, 1962.—LIVERPOOL AND DISTRICT BRANCH : Industrial Development Centre, M.A.N.W.E.B., Paradise Street, Liverpool, 1, "Causes, Effects and Calculation of Faults in Electrical Systems," 7.30 p.m.

BRITISH INSTITUTION OF RADIO ENGINEERS

Wed., Jan. 3, 1962.—London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1, Symposium on "Data Transmission," 10 a.m.

ILLUMINATING ENGINEERING SOCIETY

Wed., Jan. 3, 1962.—SWANSEA GROUP : Demonstration Theatre, South Wales Electricity Board, The Kingsway, Swansea, "Floodlighting for Industrial Situations," A. E. Fothergill, 6 p.m.
Thurs., Jan. 4, 1962.—NOTTINGHAM CENTRE : Electricity Centre, Carrington Street, Nottingham, "Lighting for Crime Detection," C. H. Edlin, 6 p.m.

INSTITUTE OF METALS

Thurs., Jan. 4, 1962.—LONDON LOCAL SECTION : 17, Belgrave Square, London, S.W.1, "New Methods of Powder Generation," K. M. Spring, 6.30 p.m.

INSTITUTE OF PETROLEUM

Wed., Jan. 3, 1962.—61, New Cavendish Street, London, W.1, "The Economics of Tanker Design," I. B. Blackwood, 5.30 p.m.

INSTITUTE OF REFRIGERATION

Thurs., Jan. 4, 1962.—Institute of Marine Engineers, Memorial Building, 76, Mark Lane, London, E.C.3, "Refrigeration in Dam Cooling," S. I. Neuman, 5.30 p.m.

INSTITUTE OF WELDING

Thurs., Jan. 4, 1962.—CHRISTMAS LECTURE FOR YOUNG PEOPLE : 54, Princes Gate, Exhibition Road, South Kensington, London, S.W.7, "Joining the Modern Way," John Strong, 11 a.m.

INSTITUTION OF ELECTRICAL ENGINEERS

Tues., Jan. 2, 1962.—NORTH MIDLAND CENTRE : Leeds and County Conservative Club, South Parade, Leeds, 1, "Progress in Oil-Filled Cables and their Accessories," A. N. Arman, F. J. Miranda and G. R. Bishop, 6.30 p.m. ★ SOUTH MIDLAND CENTRE : Town Hall, Birmingham, Faraday Lecture, "Expanding Horizons in Communications," D. A. Barron, 7 p.m.
Wed., Jan. 3, 1962.—TEES-SIDE SUB-CENTRE : Cleveland Scientific and Technical Institution, Middlesbrough, "The Application of Electrical Technology to Instruments in the Chemical Industry," J. C. Quayle, 6.30 p.m. ★ SOUTHERN CENTRE : The University, Southampton, "Short-Circuit Ratings for Main Cables," G. S. Buckingham, and "A Basis for Short-Circuit Ratings for Paper-Insulated Cables up to 11kV," L. Gosland and R. G. Parr, 7 p.m.
Thurs., Jan. 4, 1962.—ORDINARY MEETING : Savoy Place, London, W.C.2, "The Transmission of Power at High Voltages," F. J. Lane, 5.30 p.m. ★ NORTH STAFFORDSHIRE SUB-CENTRE : Victoria Hall, Hanley, Faraday Lecture, "Expanding Horizons in Communications," D. A. Barron, 7 p.m.
Fri., Jan. 5, 1962.—MEDICAL ELECTRONICS DISCUSSION GROUP : Savoy Place, London, W.C.2, Discussion on "Membranes," opened by H. Davson, 6 p.m.

INSTITUTION OF HEATING AND VENTILATING ENGINEERS

Tues., Jan. 2, 1962.—SOUTH WESTERN BRANCH : R. W. A. School of Architecture, Bristol, "The Application of Pneumatic Controls to Air Conditioning with Special Reference to High Velocity Air Conditioning," G. F. Brown, 6.30 p.m.

INSTITUTION OF MECHANICAL ENGINEERS

Tues., Jan. 2, 1962.—COVENTRY A.D. CENTRE : Grosvenor Room, Hotel Leofric, Coventry, "The Agricultural Tractor—Its Function and Design," W. J. Foxwell, 7.15 p.m.
Wed., Jan 3, 1962.—WESTERN A.D. CENTRE : Royal Hotel, Bristol, Informal Meeting, 7 p.m. ★ LUBRICATION AND WEAR GROUP : 1, Birdcage Walk, Westminster, London, S.W.1, Discussion on "Wear of Rubbing Electrical Contacts," 6 p.m.
Thurs., Jan. 4, 1962—EASTERN BRANCH : Sun Hotel, Hitchin, Herts., "Powder Metallurgy Applications," B. H. Swan, 7.30 p.m. ★ MIDLAND BRANCH : James Watt Memorial Institute, Great Charles Street, Birmingham, Repetition of the James Clayton Lecture, "Machine Tool Research, Design and Utilisation," D. F. Galloway, 6 p.m.
Fri., Jan. 5, 1962.—NORTH WESTERN BRANCH : The University, Manchester, Repetition of the Leonardo da Vinci Lecture, "The Challenge of Vertical Take-off," : Part I—"Helicopters," G. S. Hislop, and Part II—"Jet Lift," D. Keith-Lucas, 2.30 p.m.

INSTITUTION OF PLANT ENGINEERS

Tues., Jan. 2, 1962.—PETERBOROUGH BRANCH : White Lion Hotel, Church Street, Peterborough, "Rocket Propulsion and Control," D. Hurden, 7.30 p.m.
Wed., Jan. 3, 1962.—LEICESTER BRANCH : Grand Hotel, Leicester, "Safety of an Electrical Installation," F. Noakes, 7.30 p.m. ★ SOUTHERN BRANCH : Polygon Hotel, Southampton, Forum on "Engineering Education and Training," 7.30 p.m.
Thurs., Jan. 4, 1962.—BIRMINGHAM BRANCH : Hotel Leofric, Coventry, Open Forum, 7.30 p.m.

INSTITUTION OF PRODUCTION ENGINEERS

Wed., Jan. 3, 1962.—MIDLANDS REGION : Wolverhampton and Staffs. College of Technology, Wolverhampton, "Recent Developments in Automatic and Semi-Automatic Welding," L. H. Morgan, 7.15 p.m.

INSTITUTION OF STRUCTURAL ENGINEERS

Fri., Jan. 5, 1962.—MIDLAND COUNTIES GRADUATES' AND STUDENTS' SECTION : Engineering Centre, Birmingham, "Elevated Roadways," G. B. Smedley, 6.30 p.m. ★ WESTERN COUNTIES BRANCH : Queen's Building, University Walk, Bristol, "A Mobile Tower for Servicing Rockets," F. K. Fennell, 6 p.m. ★ SOUTH WESTERN COUNTIES SECTION : Duke of Cornwall Hotel, Plymouth, "Aluminium Structures wih Particular Reference to Bridges," R. M. Davis, 6 p.m.

JUNIOR INSTITUTION OF ENGINEERS

To-day, Dec. 29.—Pepys House, 14, Rochester Row, Westminster, London, S.W.1, "The Turn of the Century : A Pictorial Survey," J. Foster Petree, 7 p.m.

NEWCOMEN SOCIETY

Wed., Jan. 3, 1962.—Lecture Theatre, Science Museum, South Kensington, London, S.W.7, "William Wood and the Coke-Smelting Process,' M. W. Flinn, 5.30 p.m.

PLASTICS INSTITUTE

Tues., Jan 2, 1962.—MIDLANDS SECTION: Grand Hotel, Leicester, "Education in the Rubber and Plastics Industries," F. H. Cotton, 6.45 p.m.
Wed., Jan. 31, 1962.—NORTH-EASTERN SECTION : Eldon Grill, Eldon Buildings, Grey Street, Newcastle upon Tyne, 1, "Foamed UF Resins and Expanded Plastics," W. Massingham, 7 p.m.
Fri., Jan. 5, 1962.—YOUNG PEOPLE'S LECTURE : Lecture Theatre, Institution of Electrical Engineers, Savoy Place, London, W.C.2, "Nature's Plastics," M. Stacey, 2.30 p.m.

ROYAL INSTITUTION OF CHARTERED SURVEYORS

Tues. and Wed., Jan. 2 *and* 3, 1962.—CHRISTMAS HOLIDAY LECTURES AND EXHIBITION : 12, Great George Street, London, S.W.1, "Map-making To-day," W. A. Seymour and D. L. Griffith Lectures, 10.30 a.m. and 2.30 p.m. Exhibition, 9.30 a.m. to 5 p.m.

SOCIETY OF INSTRUMENT TECHNOLOGY

Wed., Jan. 3, 1962.—SOUTH YORKSHIRE SECTION : Brown-Firth Research Laboratories, Princess Street, Sheffield, 4, Films, 7 p.m.
Fri., Jan. 5, 1962.—FAWLEY SECTION : Room 4a, Administration Building, Esso Petroleum Company Ltd., Fawley, "Measurement of Flow," J. Singer, 5.45 p.m.

END OF VOLUME 212

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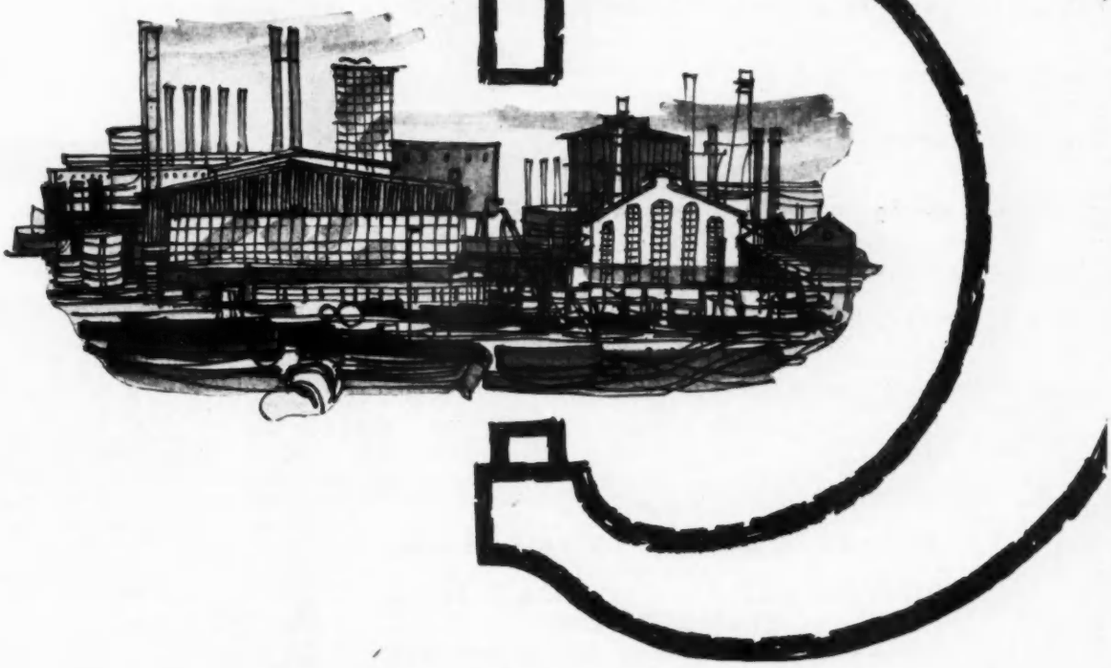

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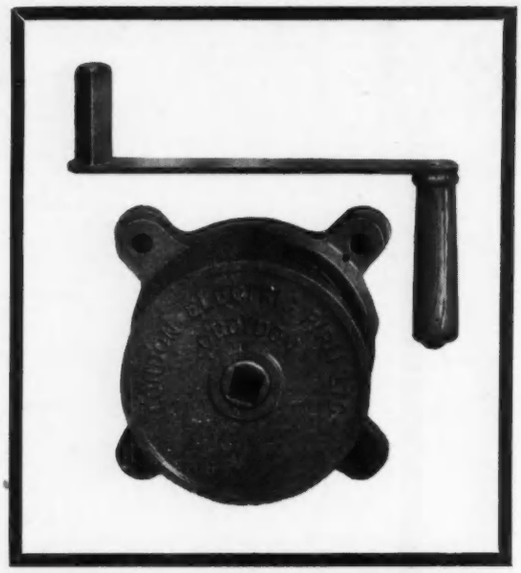

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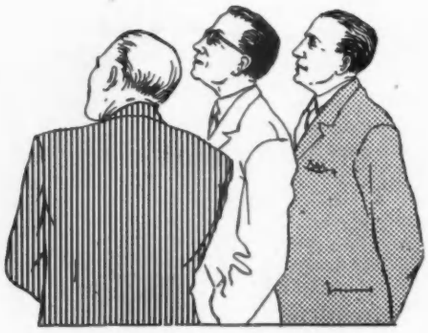

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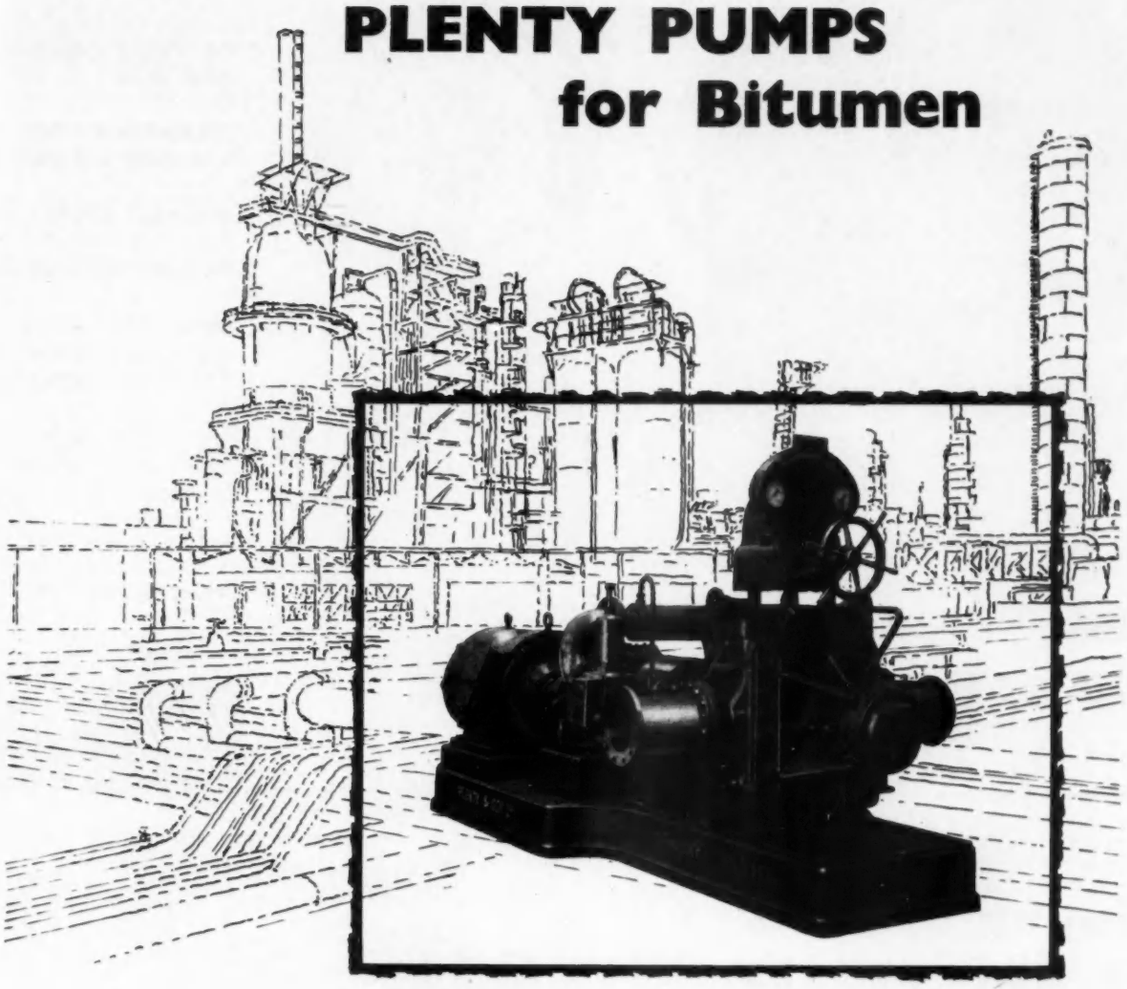

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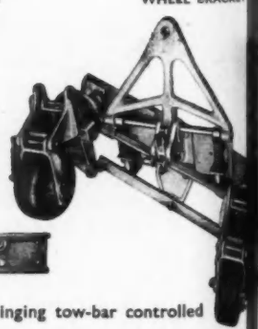

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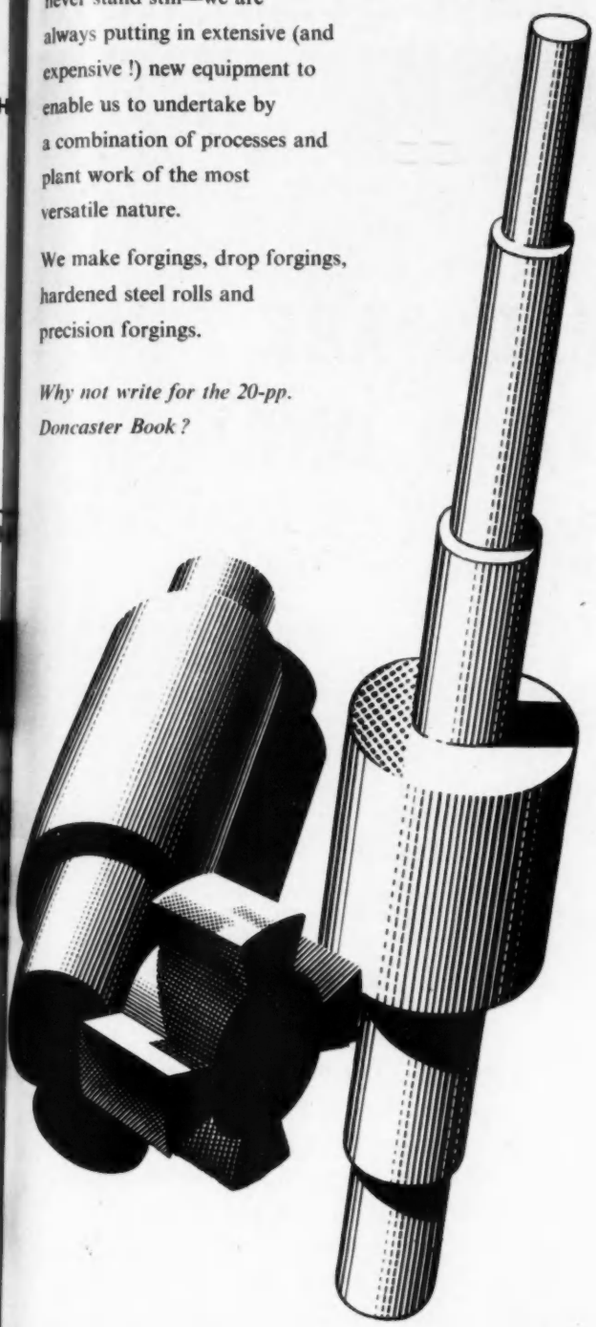

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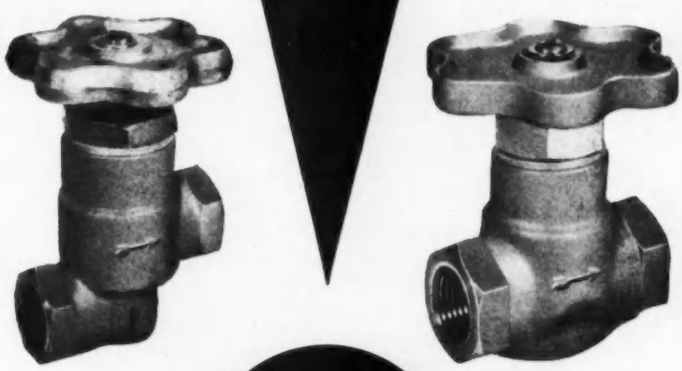

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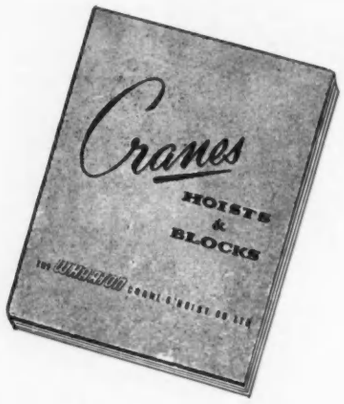

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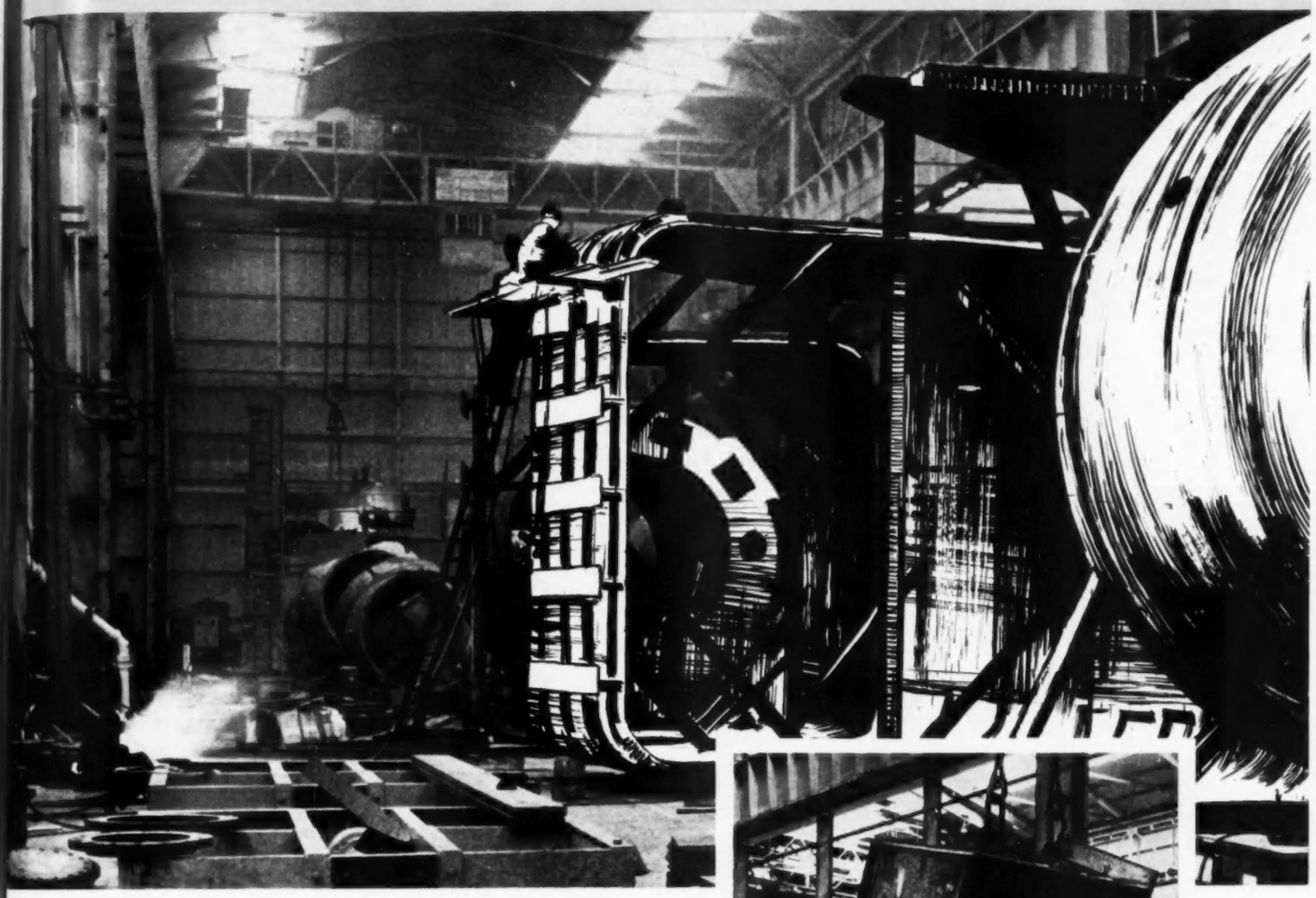

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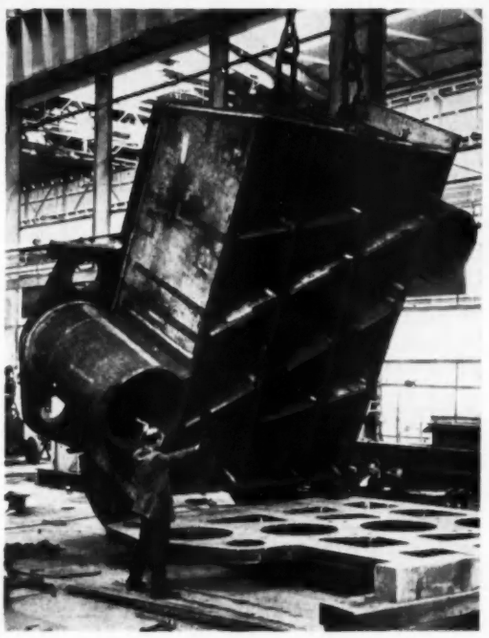

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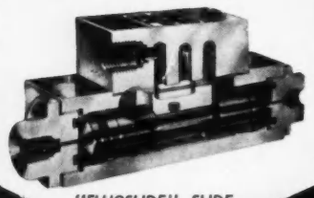

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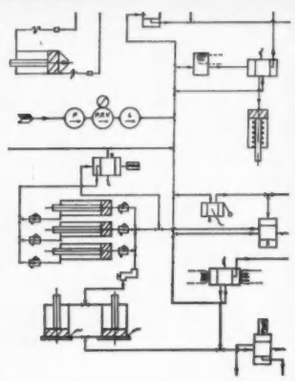

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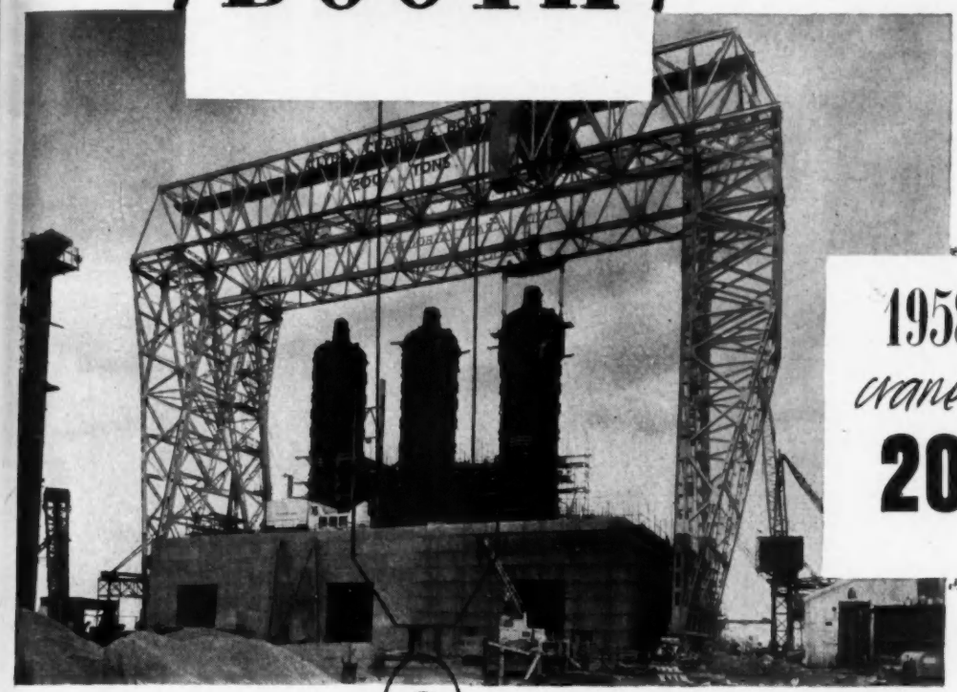

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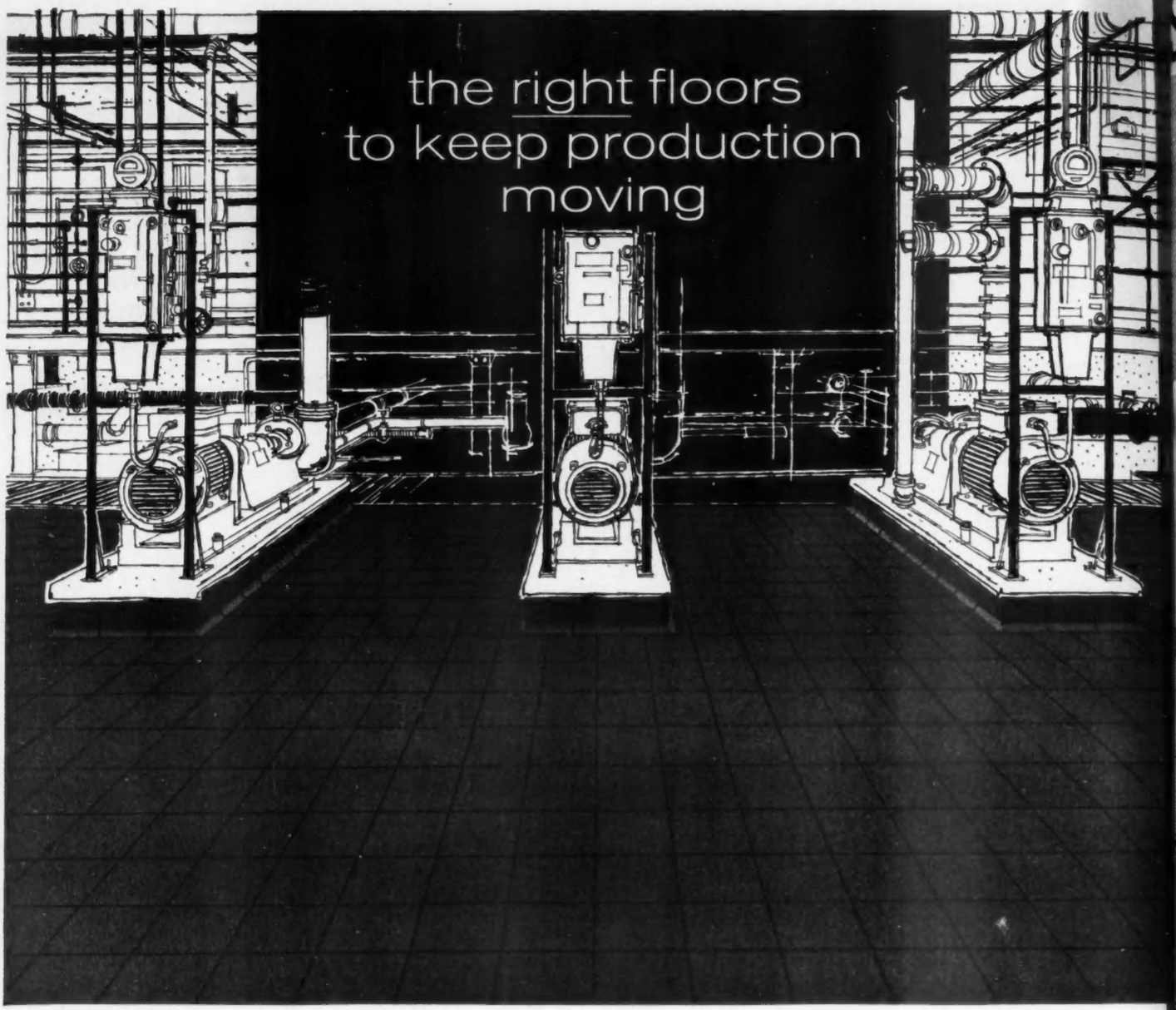
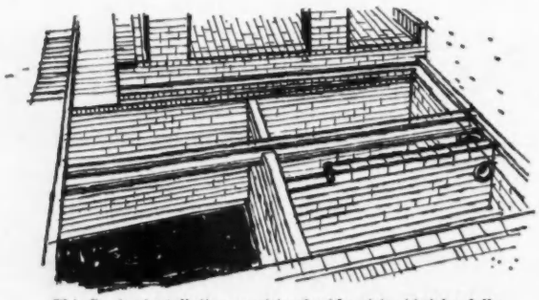


A SEMTEX FURANE RESIN CEMENT INSTALLATION AT SHELL CHEMICAL COMPANY'S STANLOW CHEMICAL PLANT



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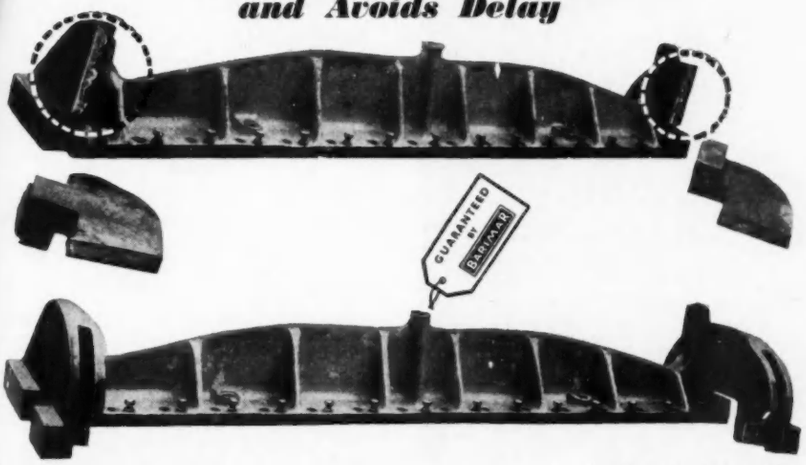

Sturdy they may be, but guillotines and similar machines in industrial use are peculiarly prone to breakdown. Overloads, bad adjustment, blunt knives, unsuitable materials—all these can result in serious fractures in "key" machines which delay production "all along the line".

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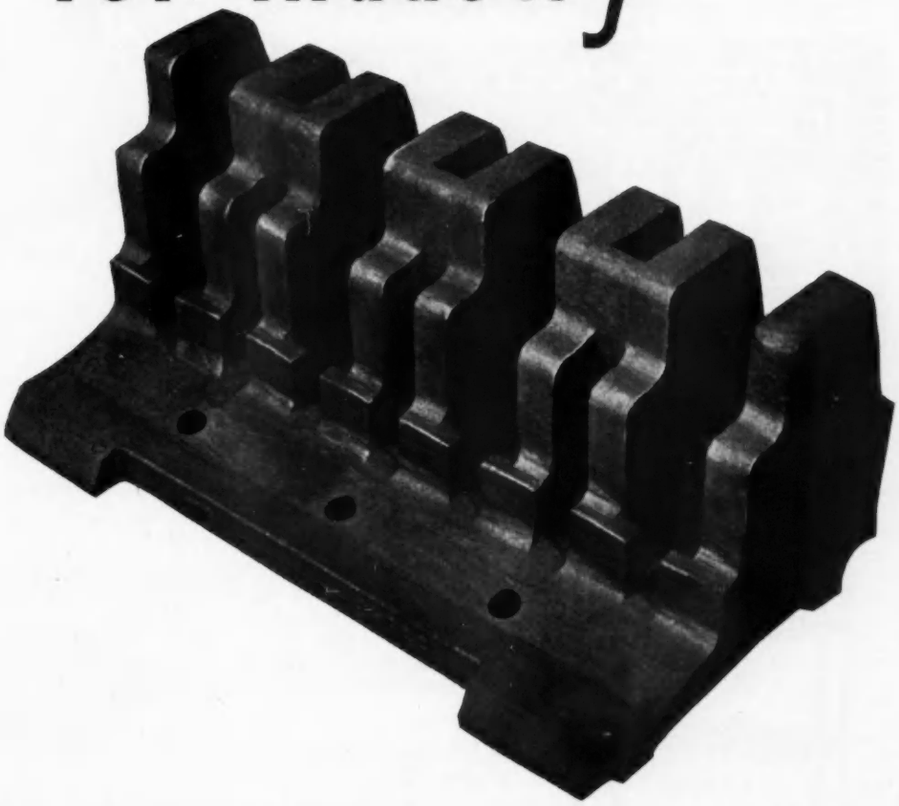

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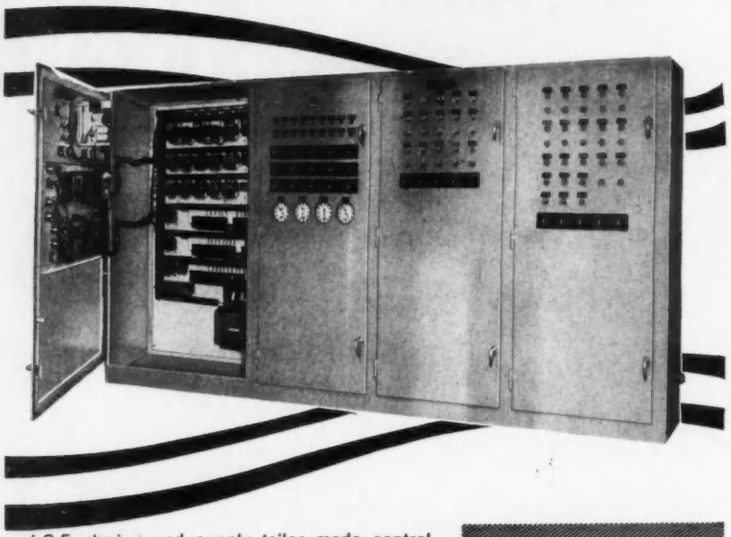

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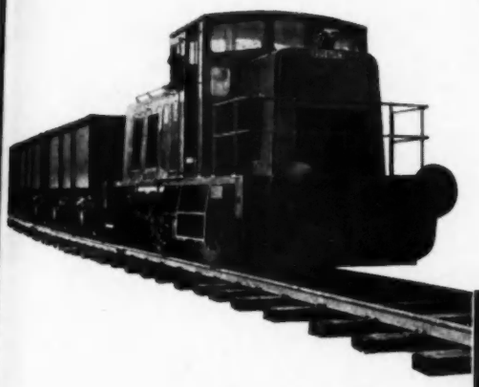

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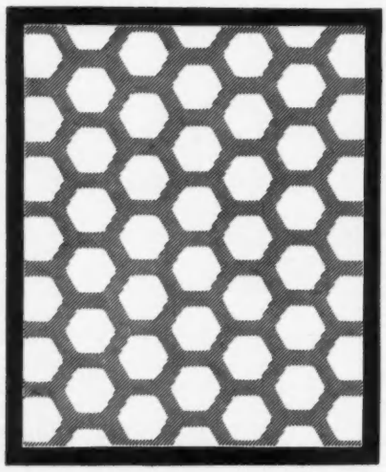

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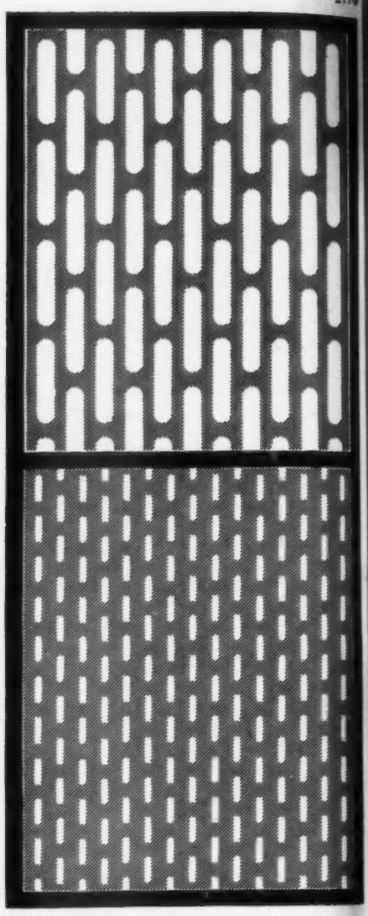

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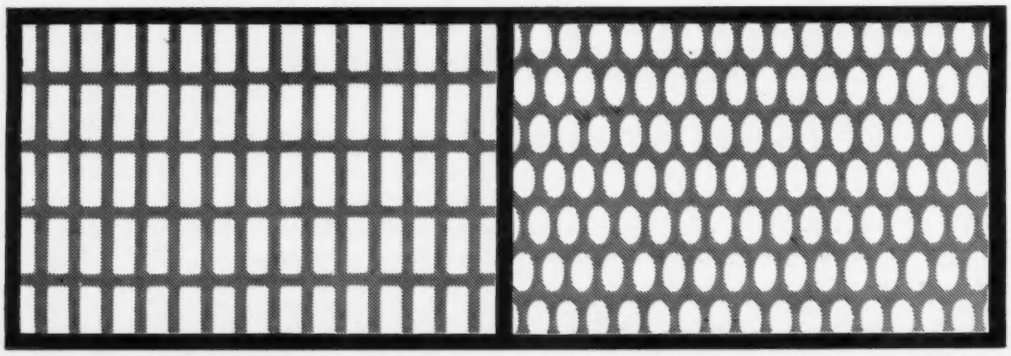

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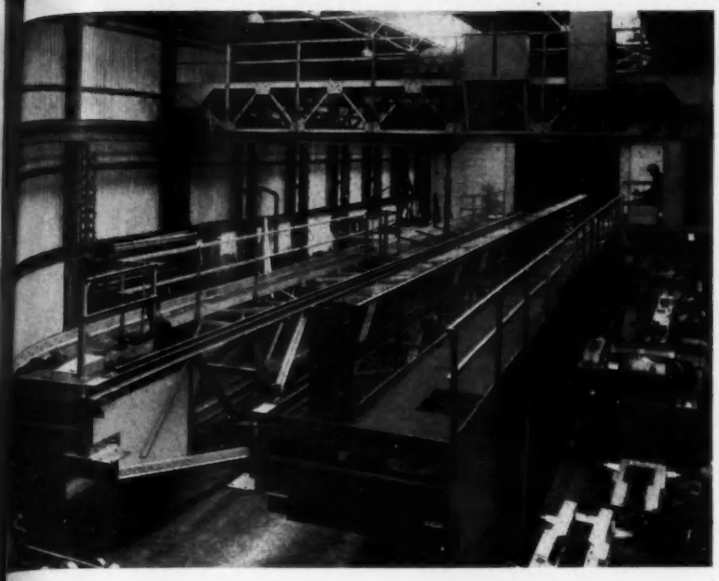

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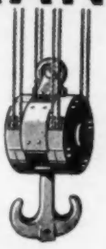

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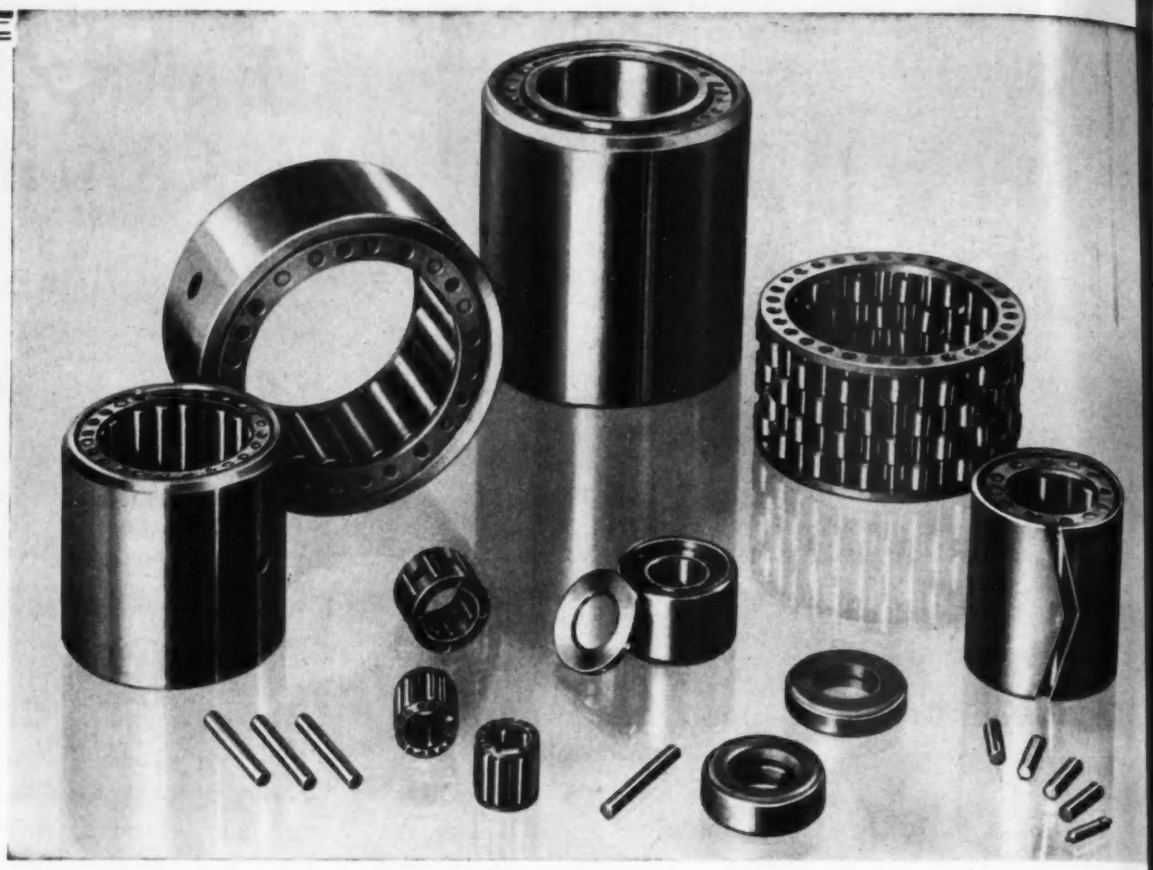

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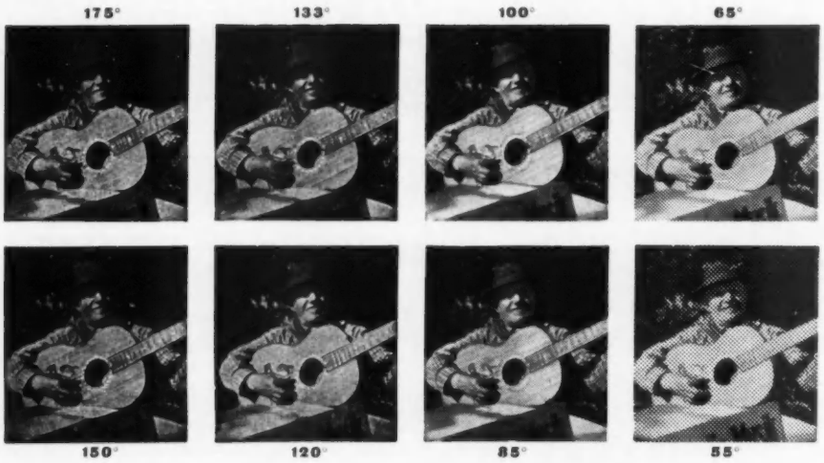

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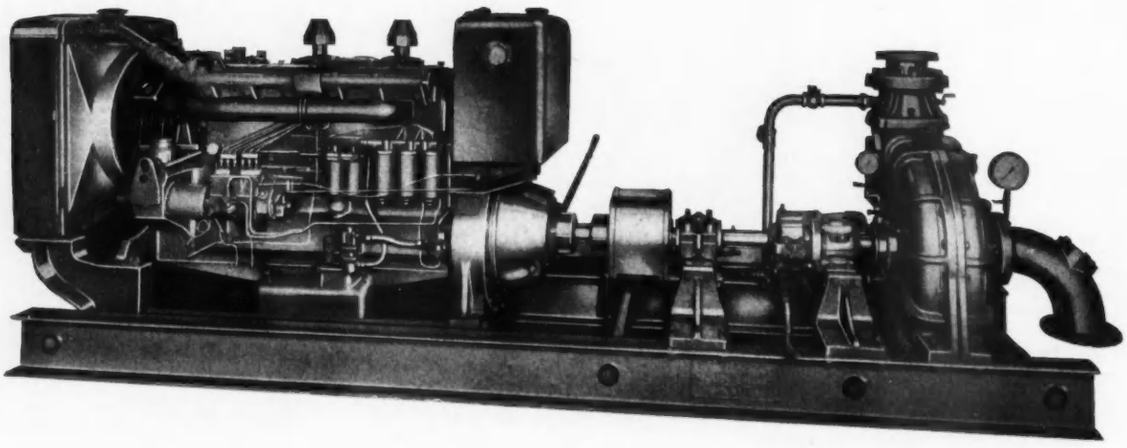

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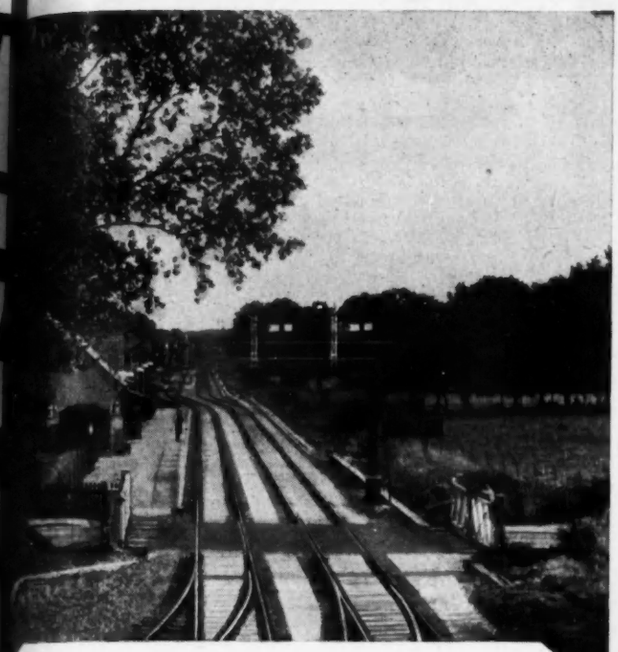

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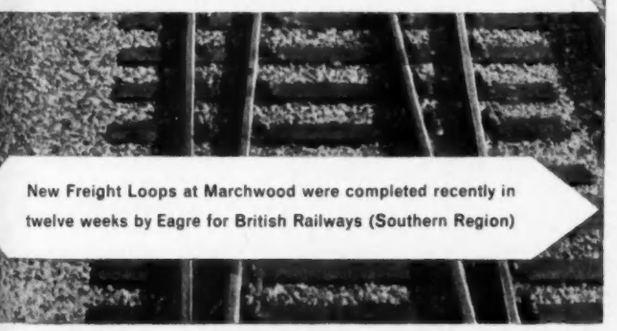

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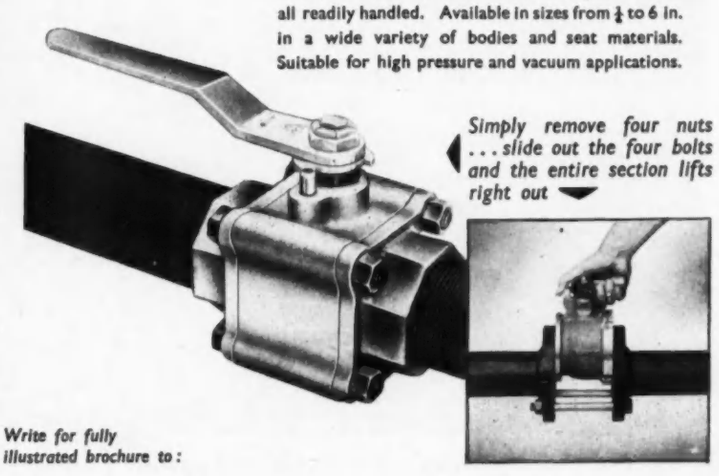

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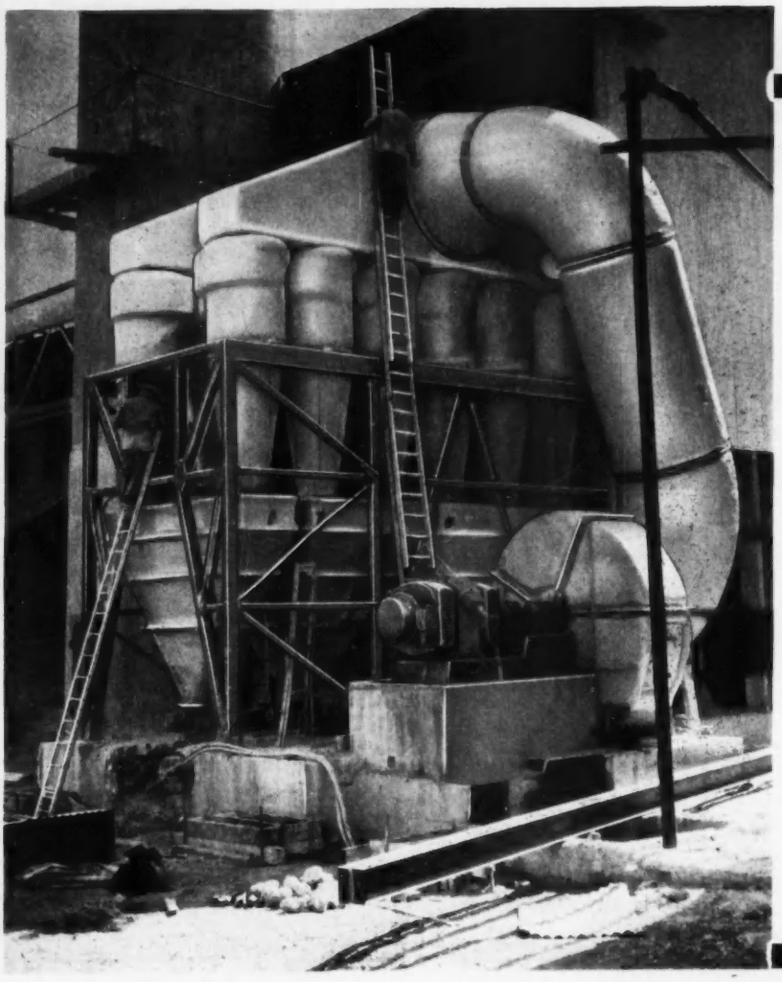

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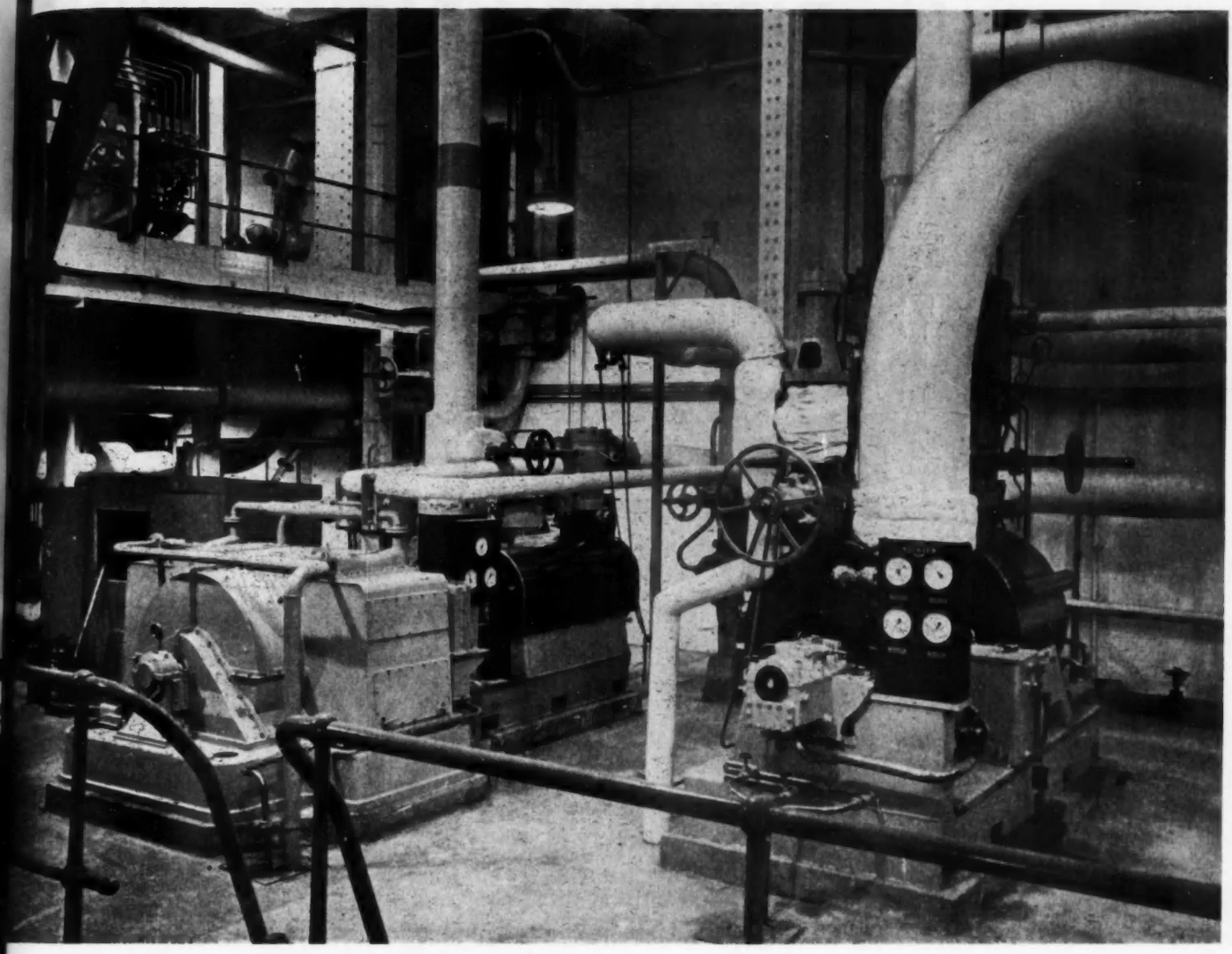

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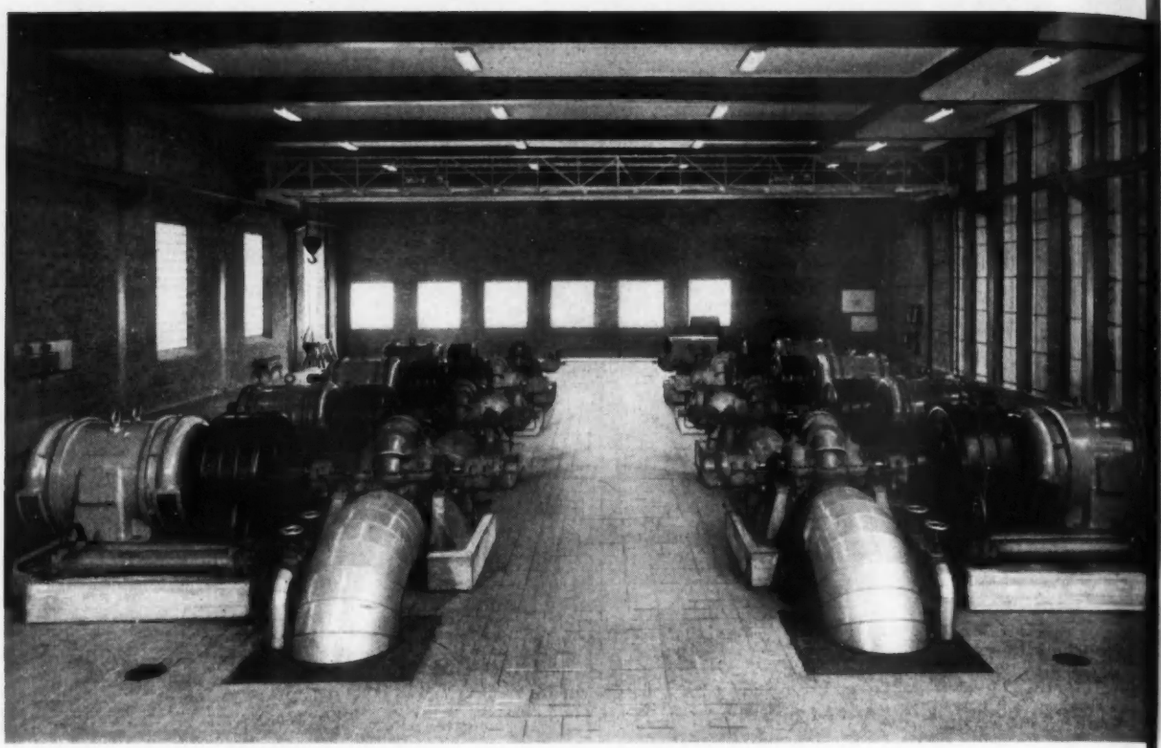

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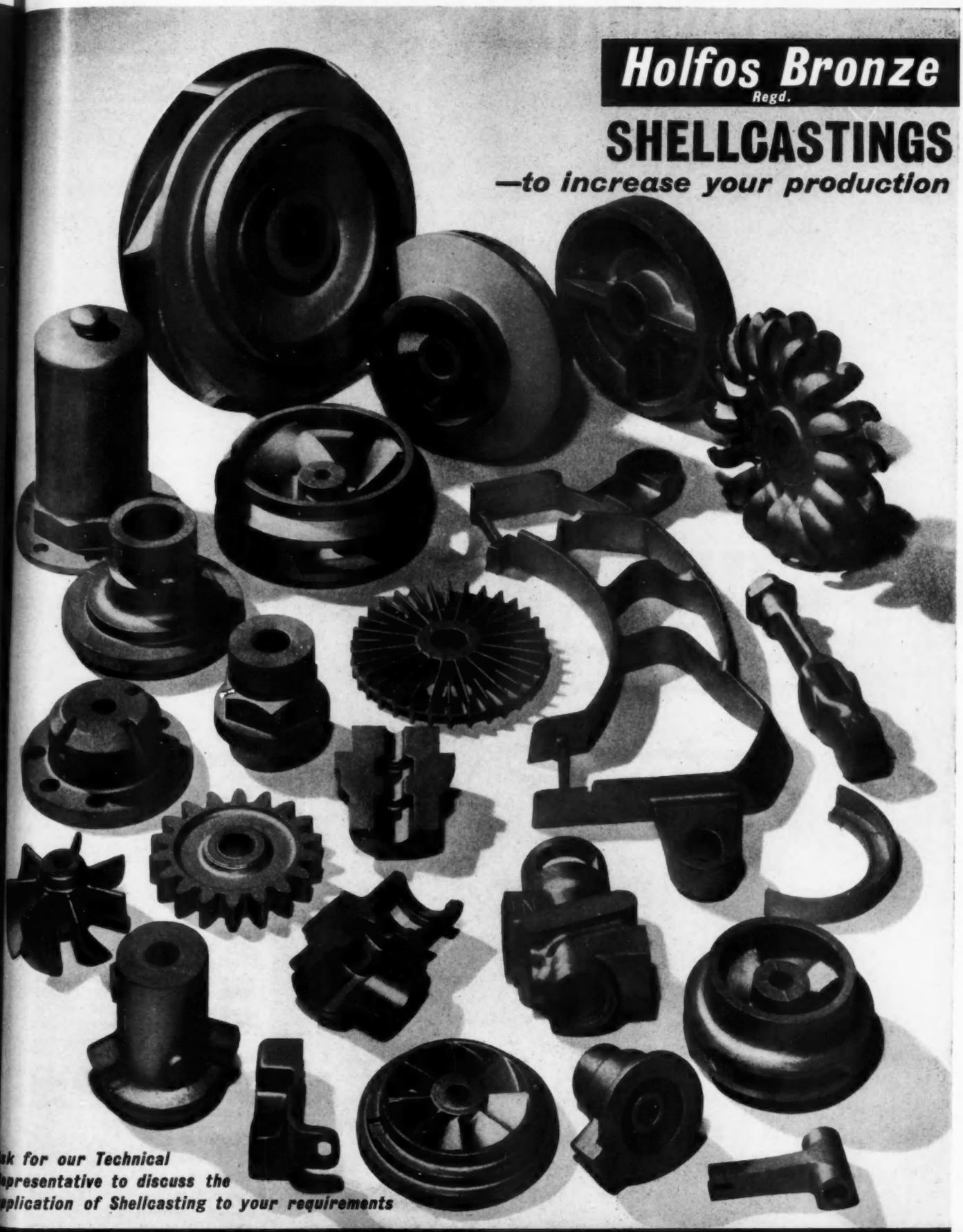

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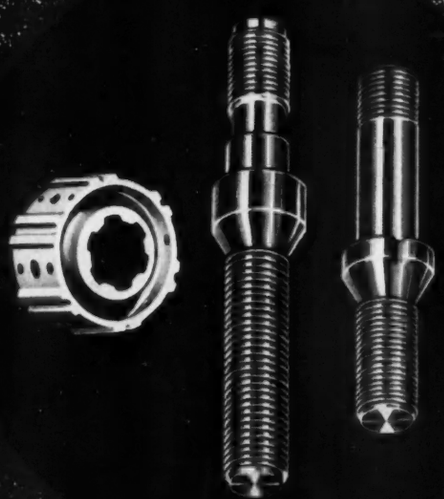

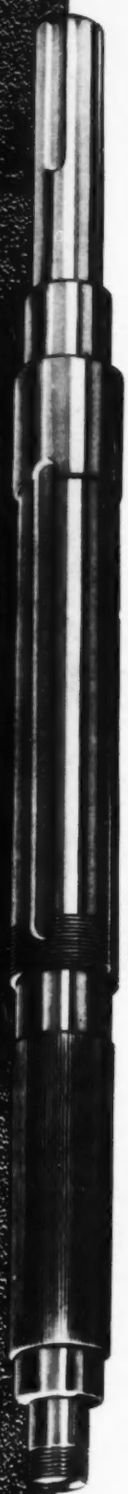

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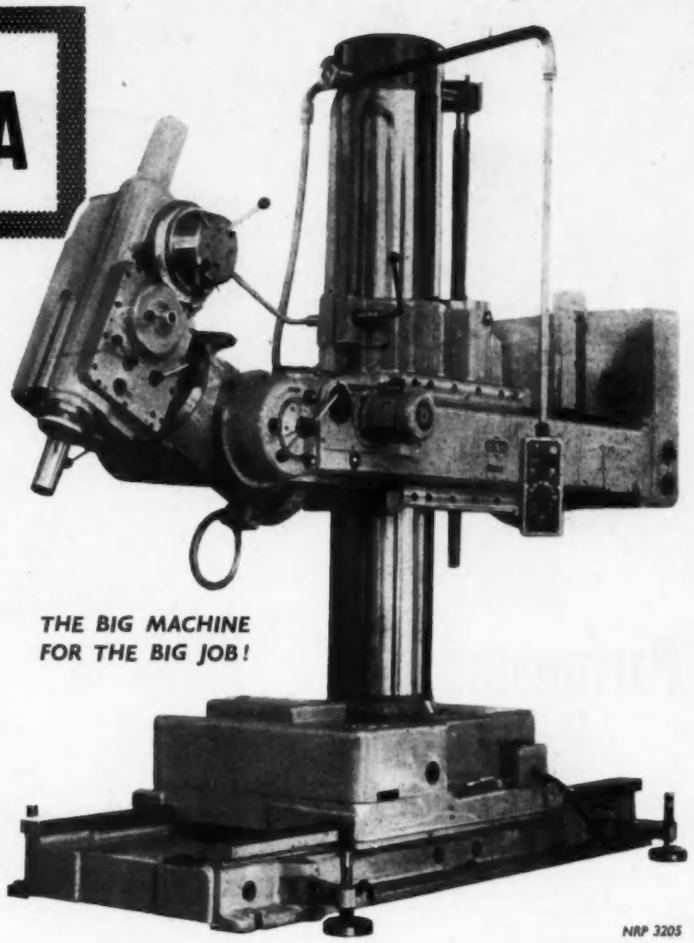

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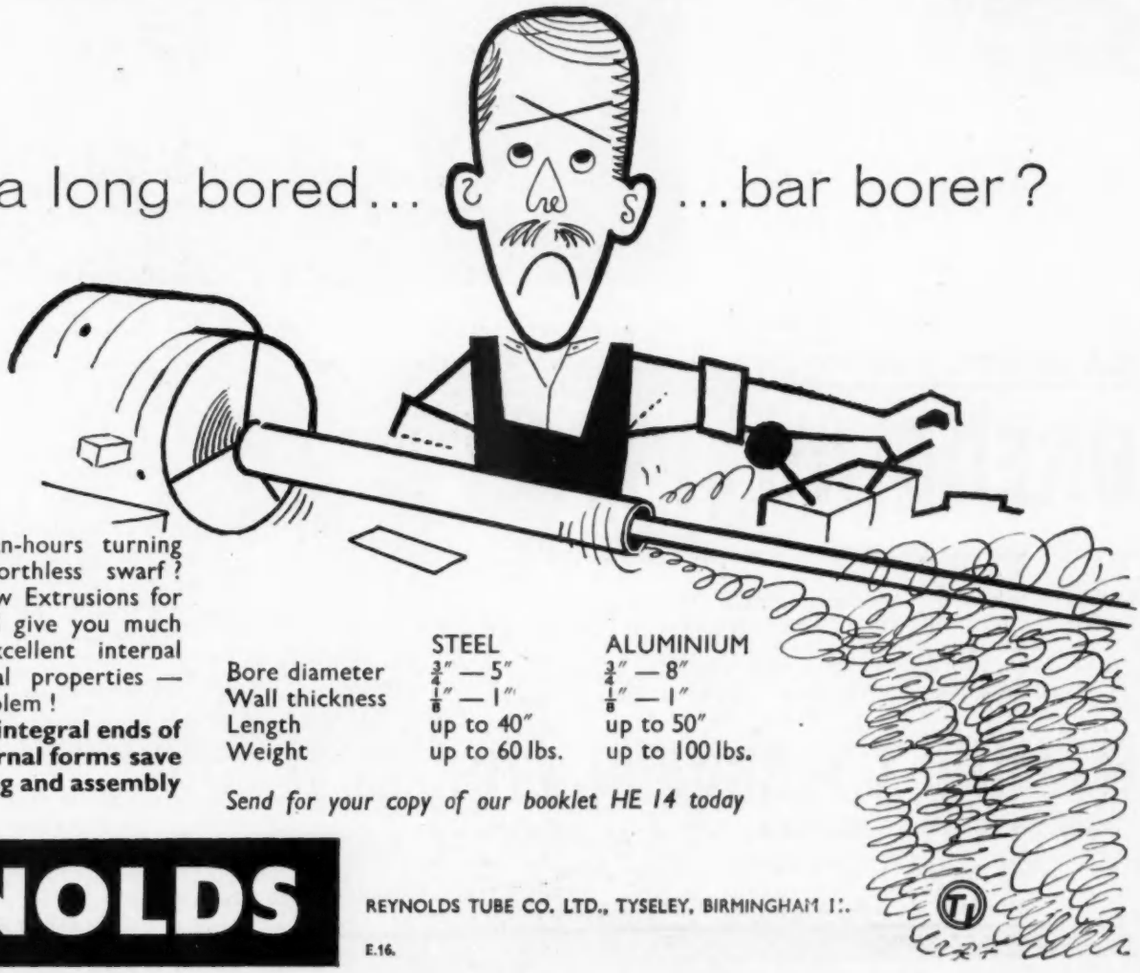

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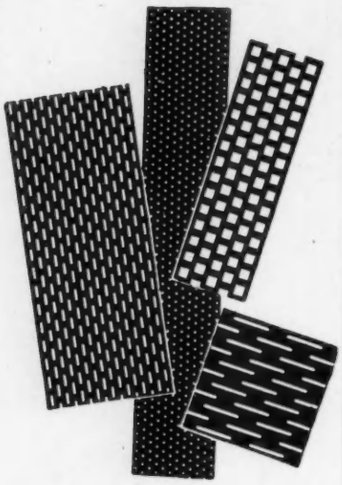

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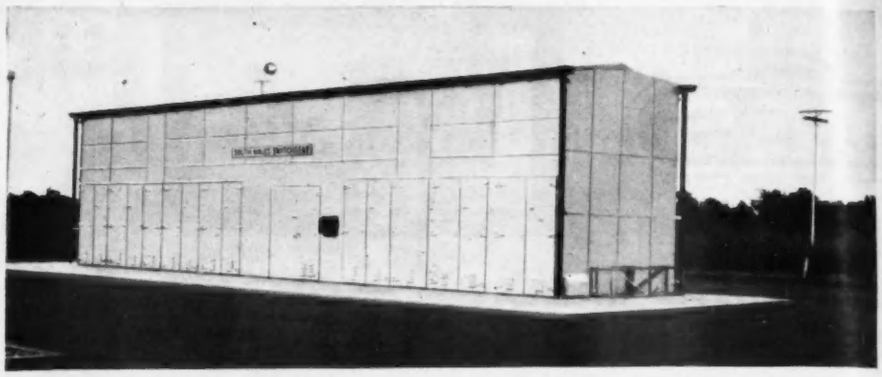

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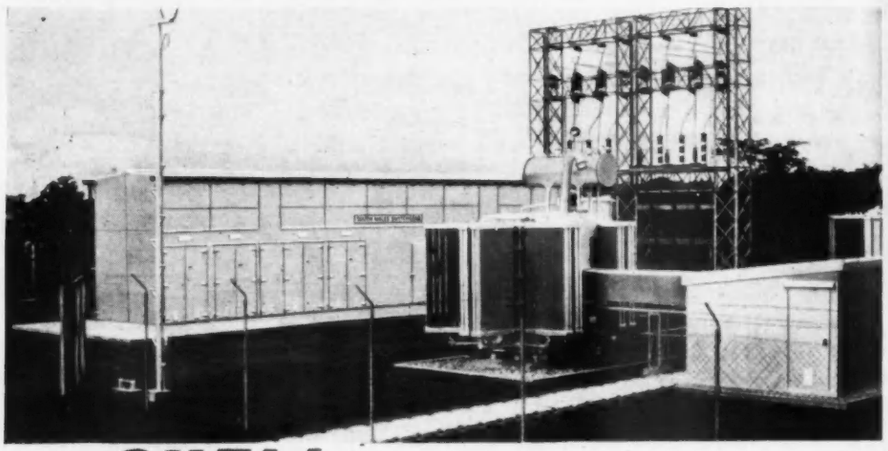

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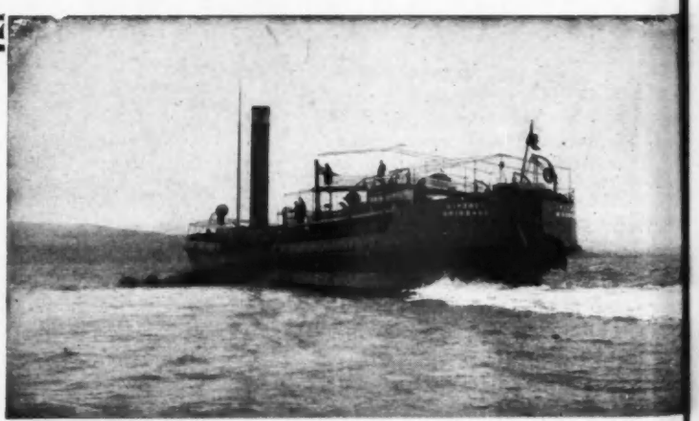

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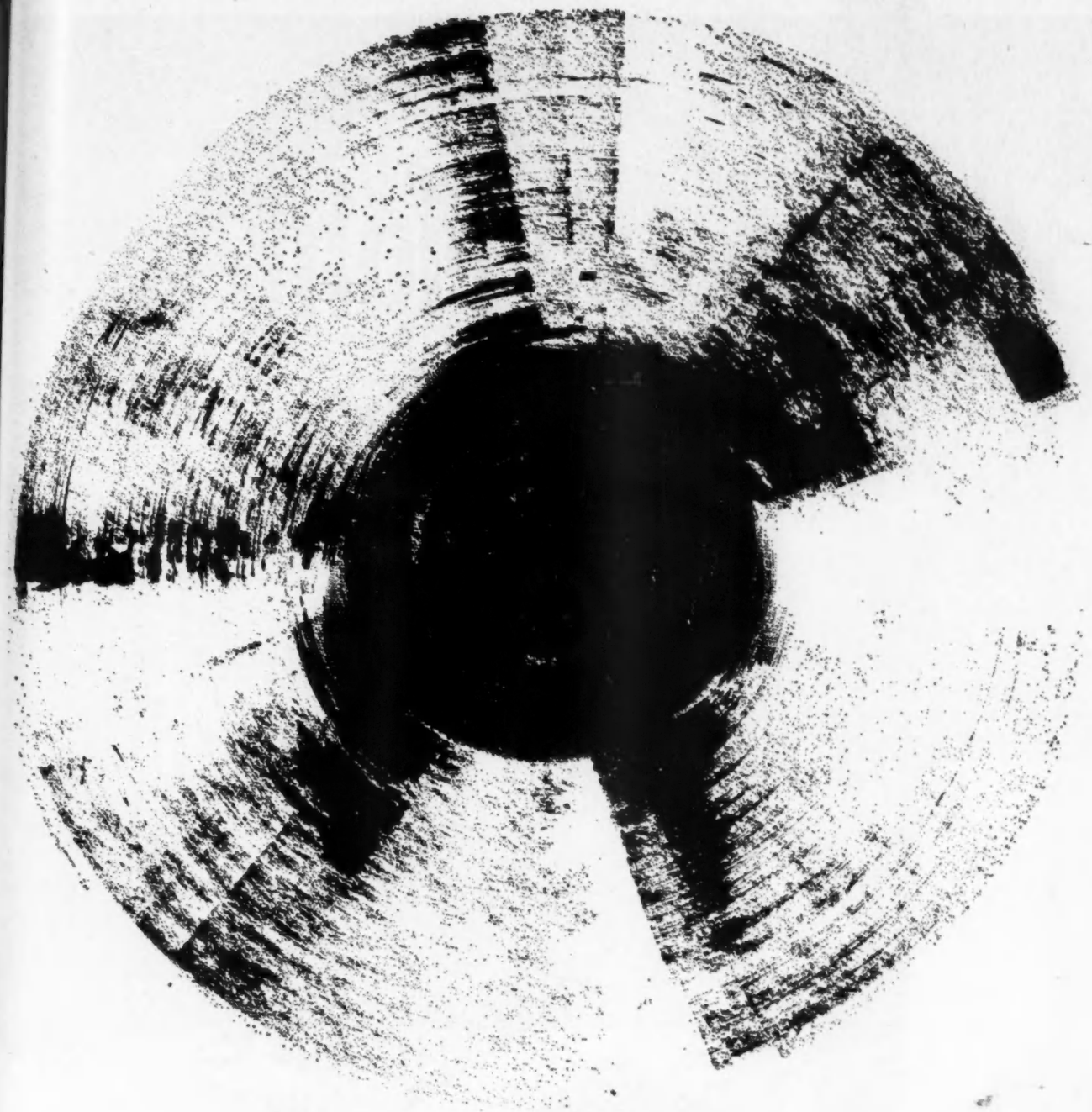

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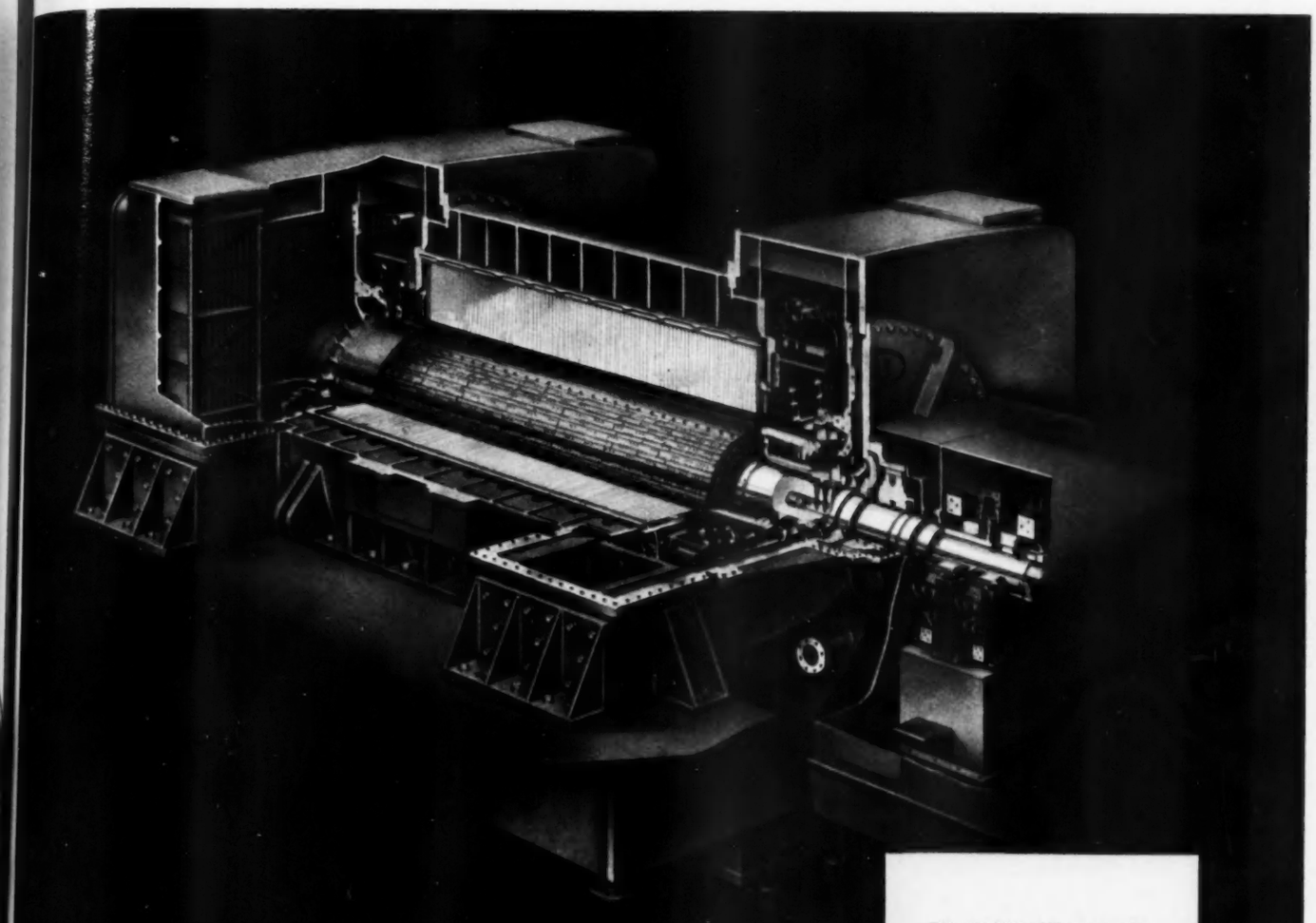

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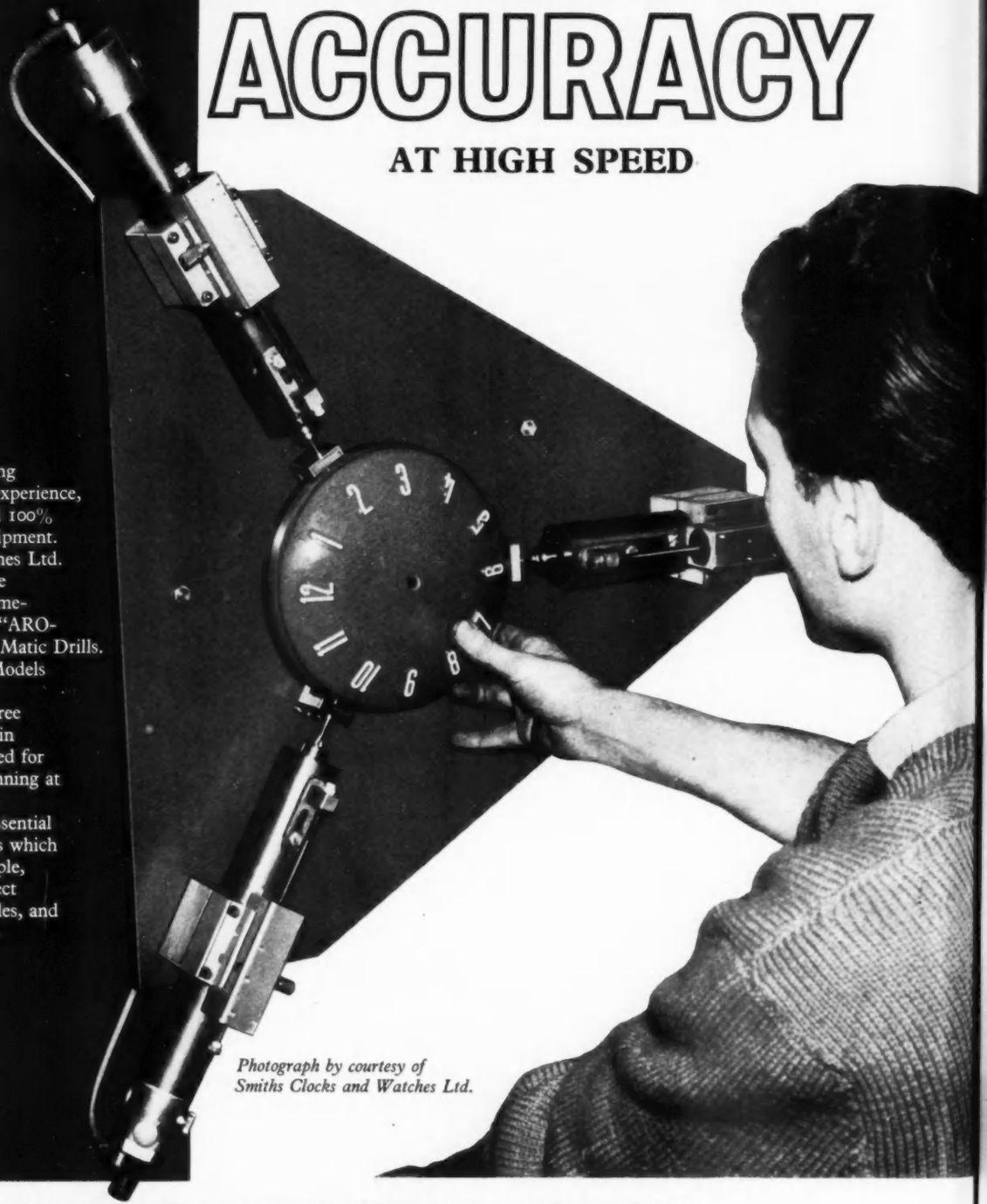

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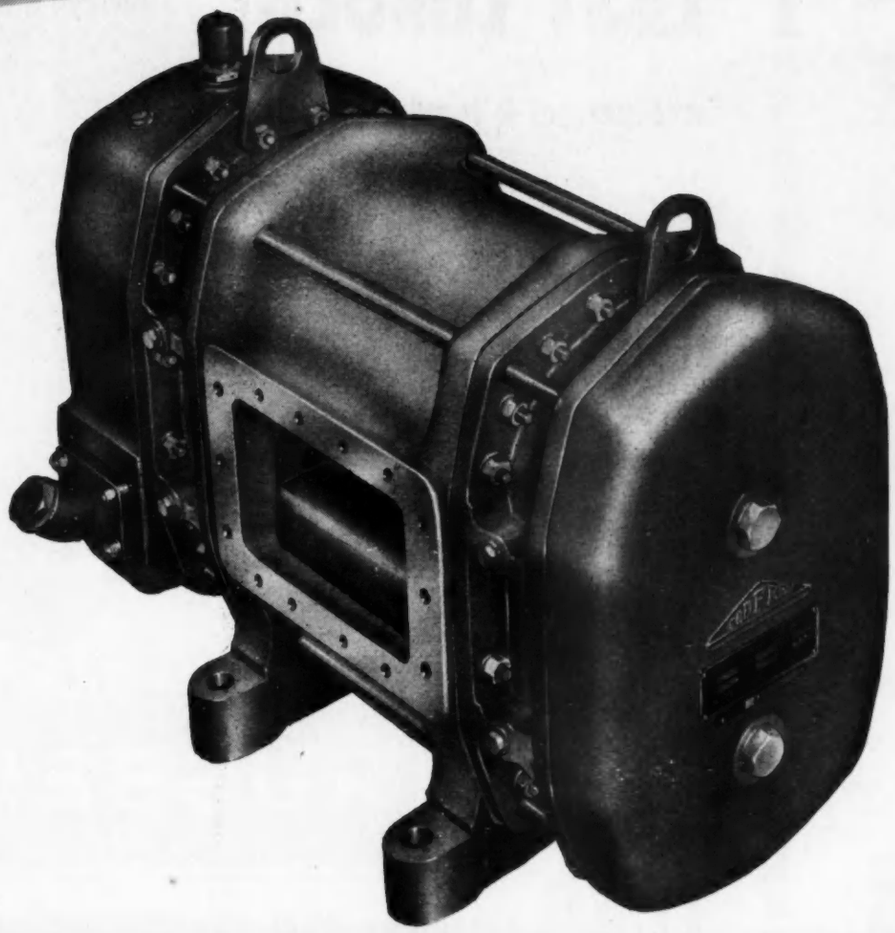

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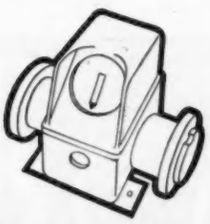

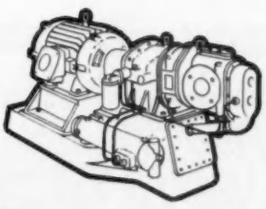

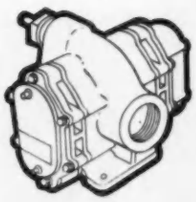

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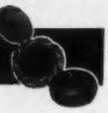

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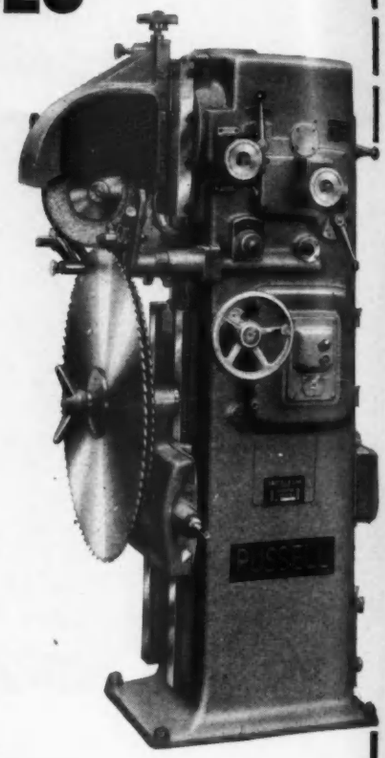

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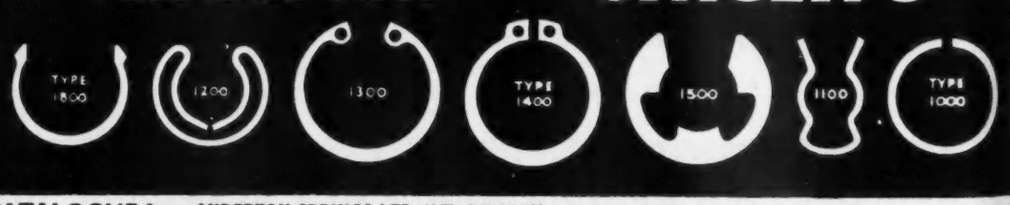

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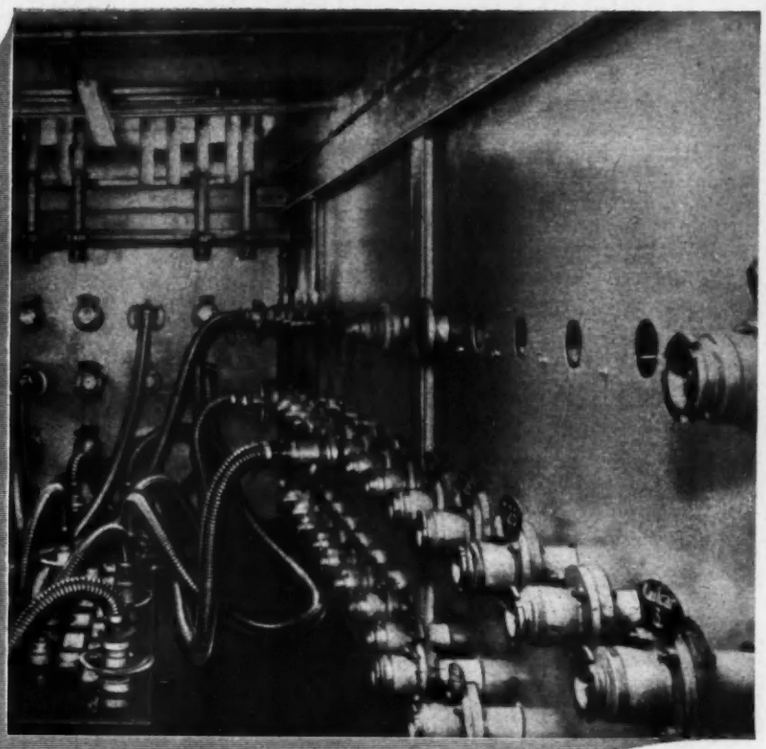

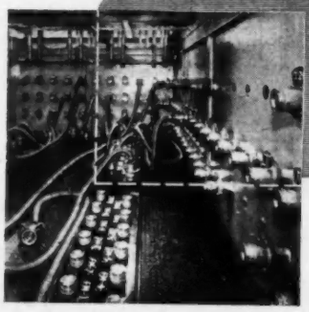

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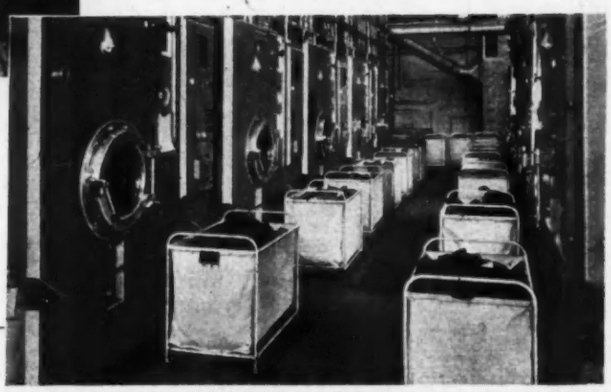

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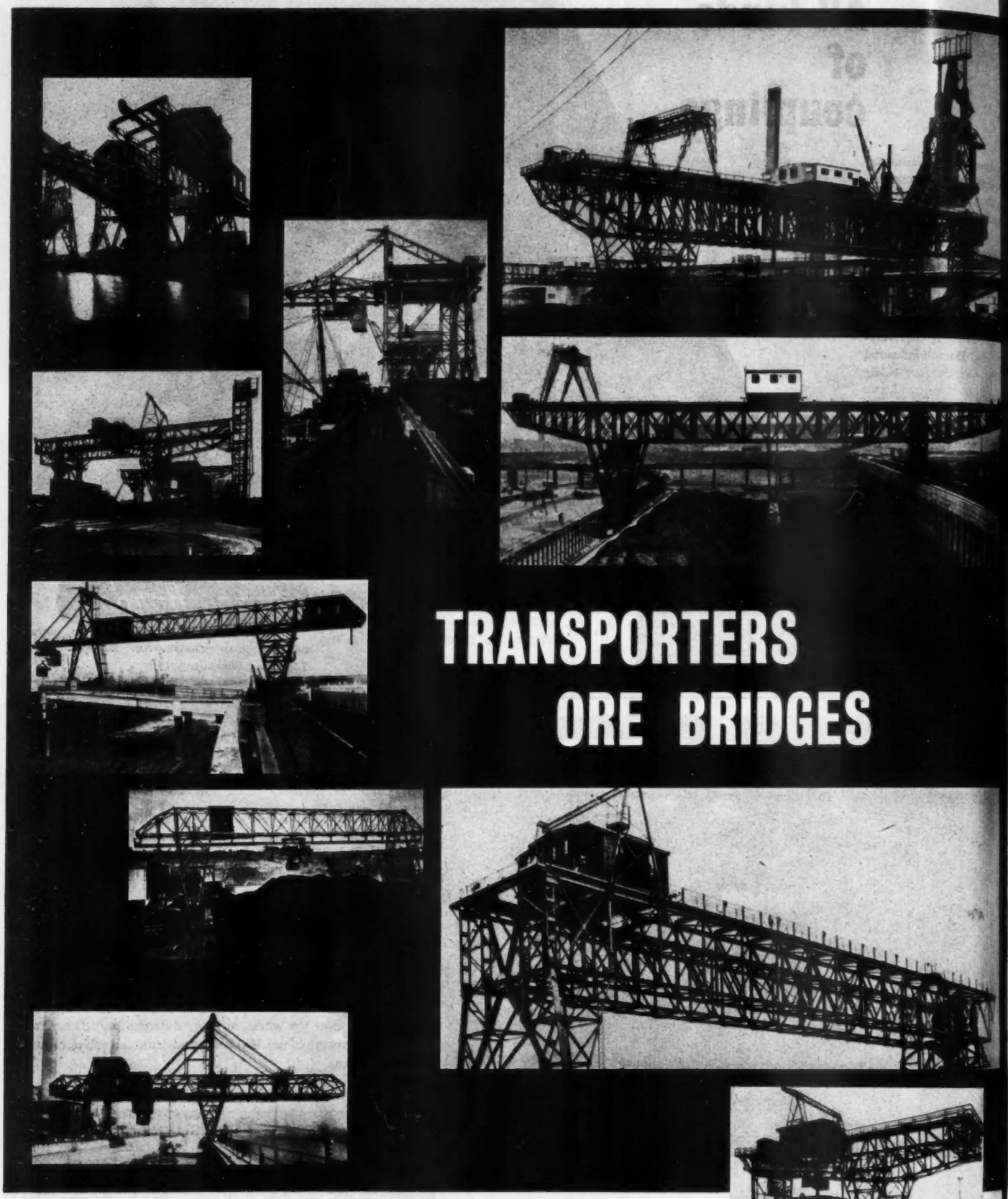

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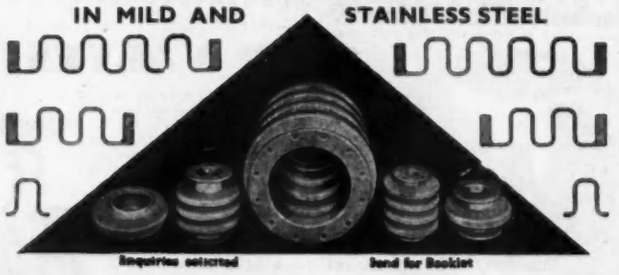

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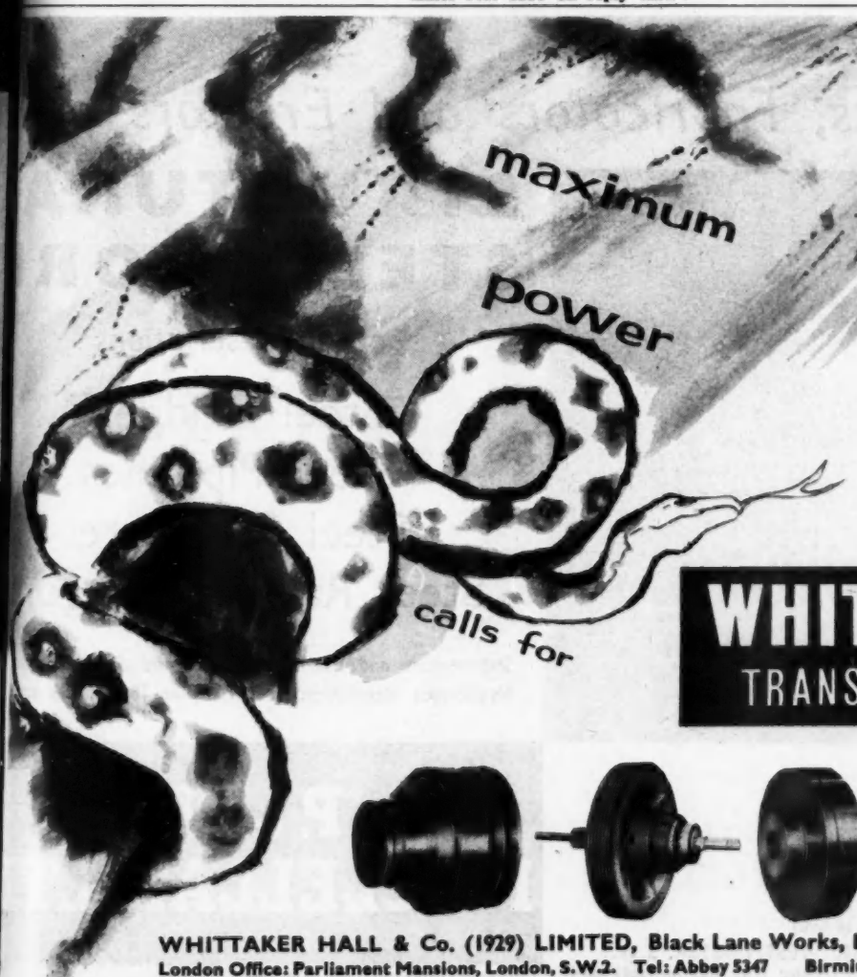

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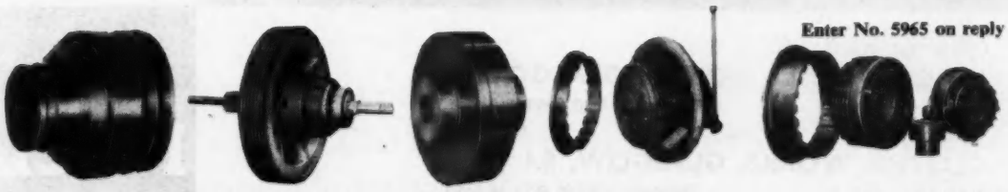

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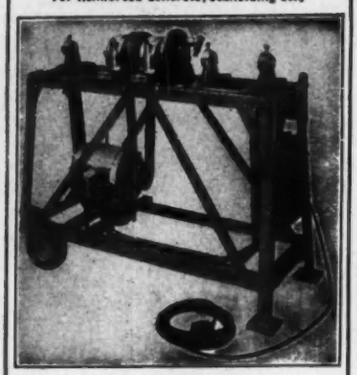

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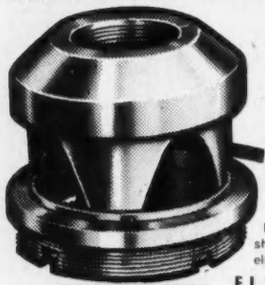

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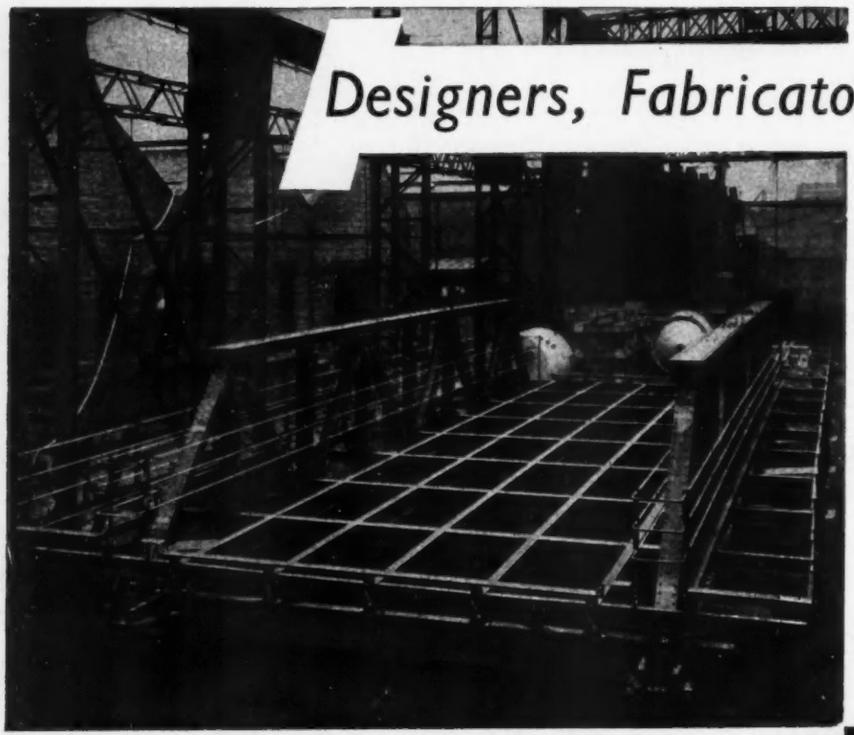

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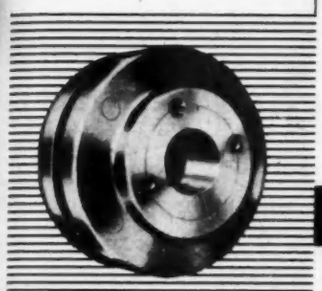

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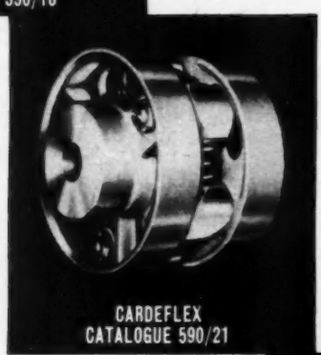

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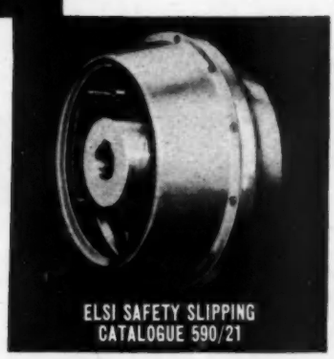

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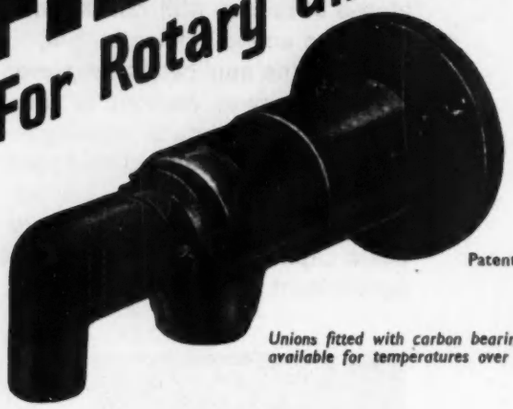

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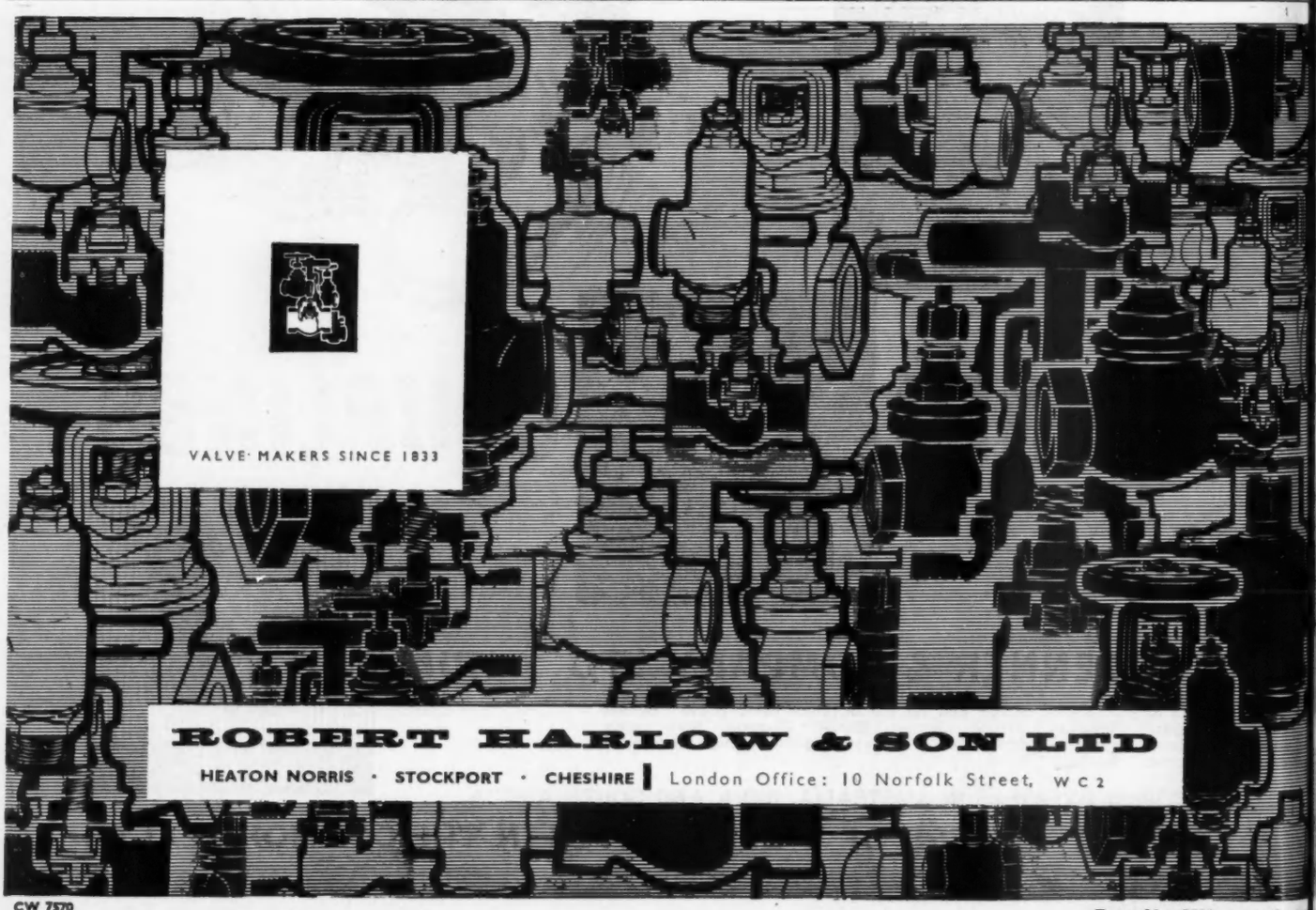

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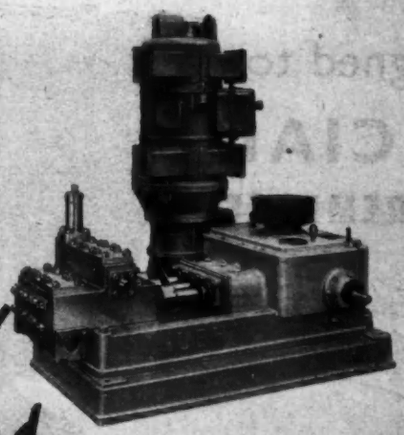

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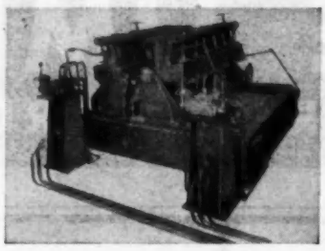

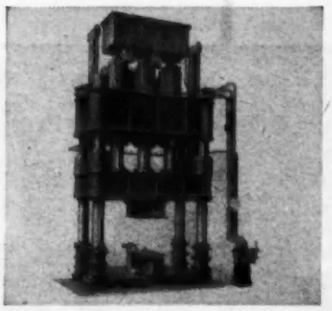

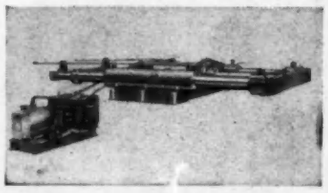

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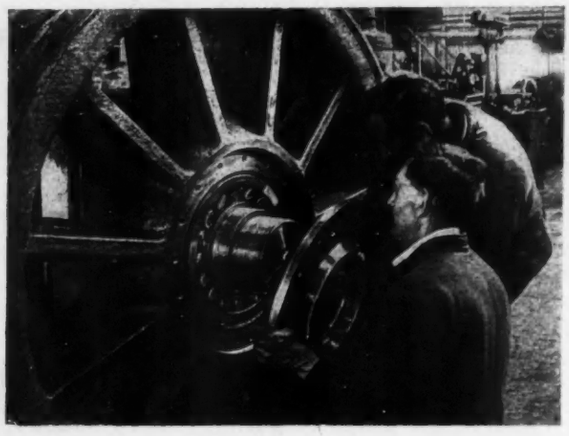

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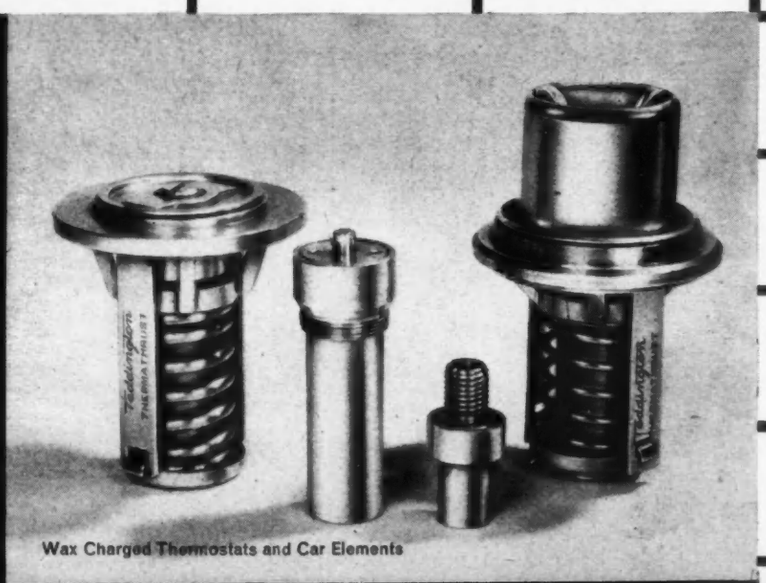

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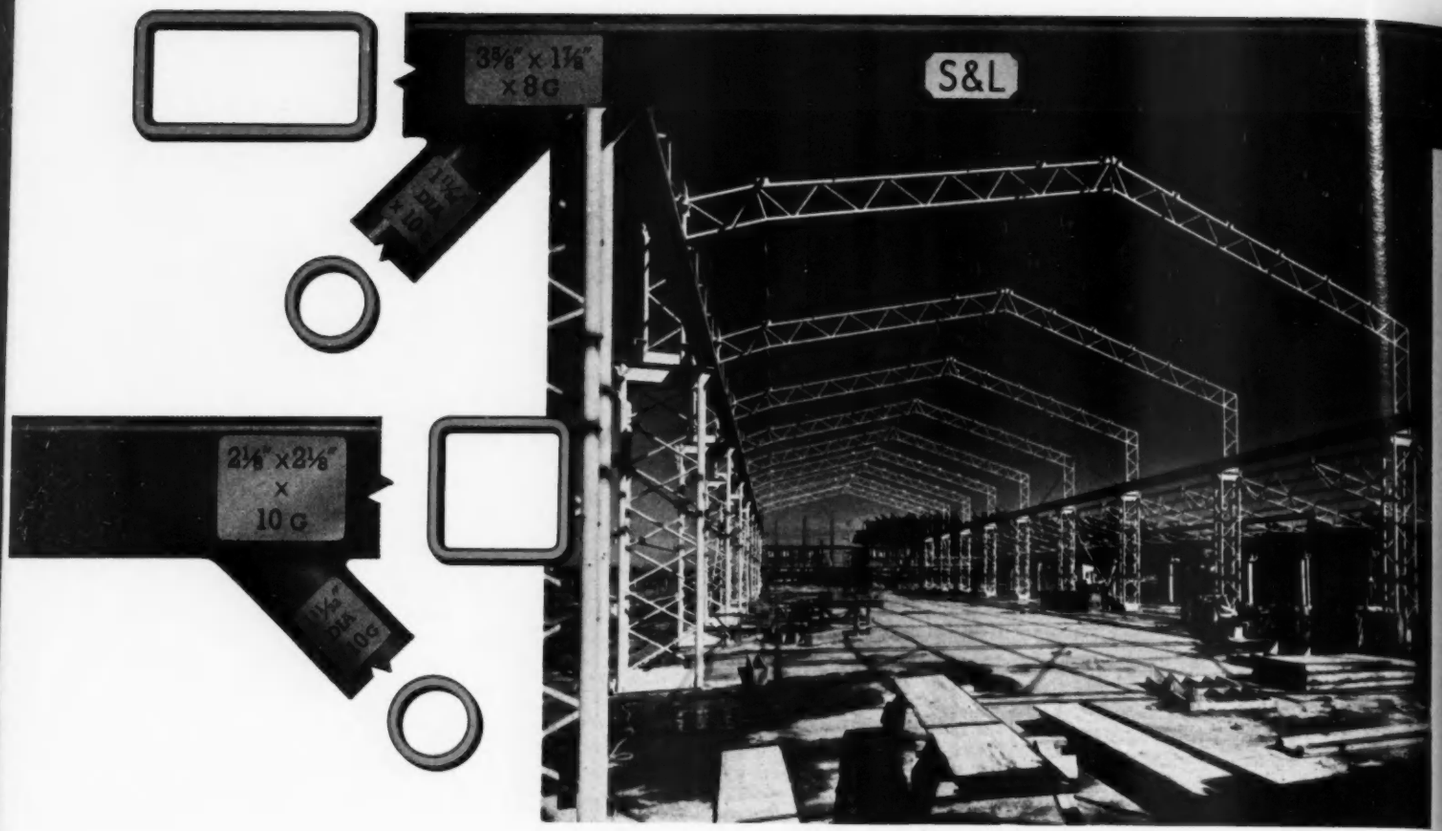

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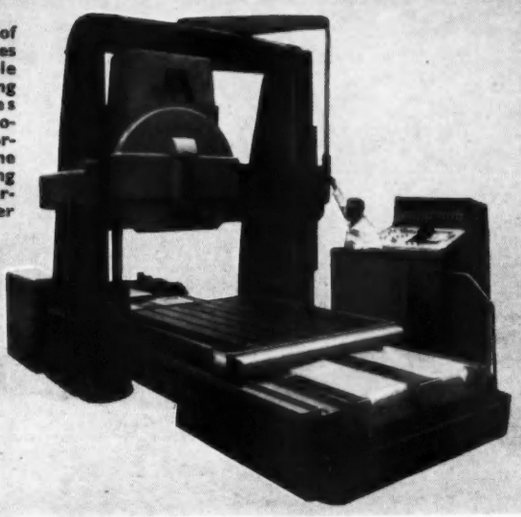

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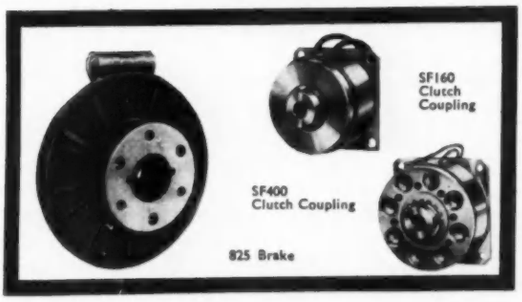

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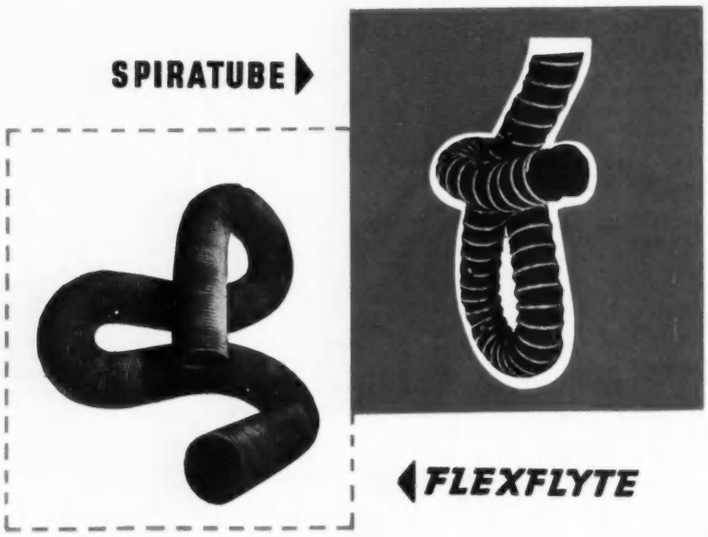

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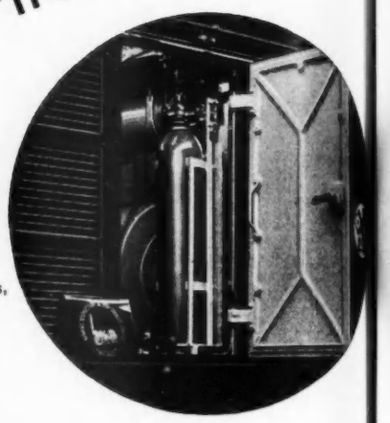

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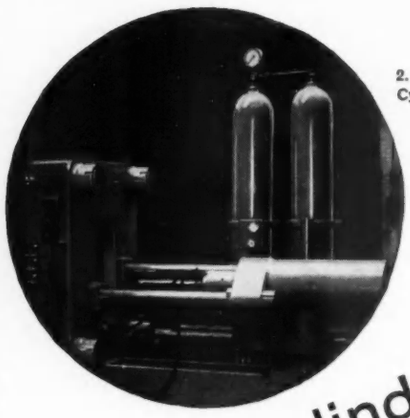

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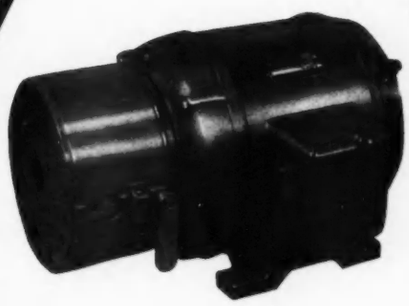

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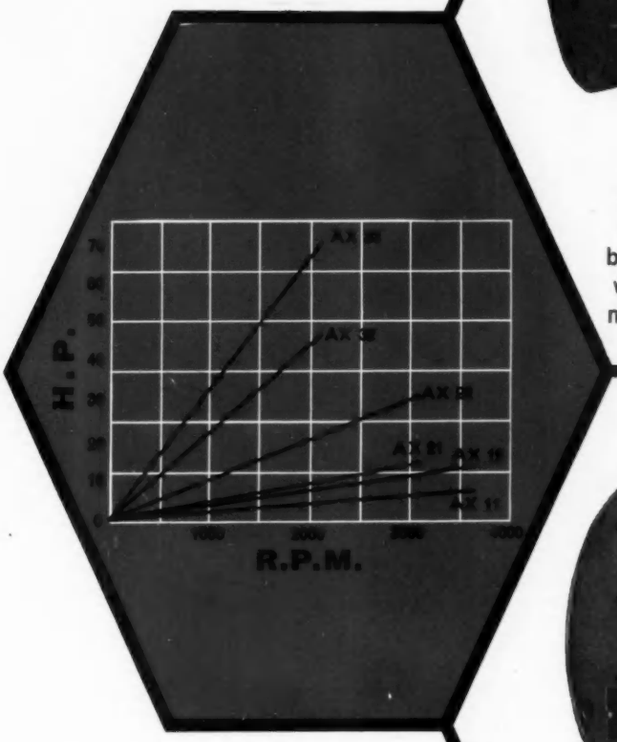

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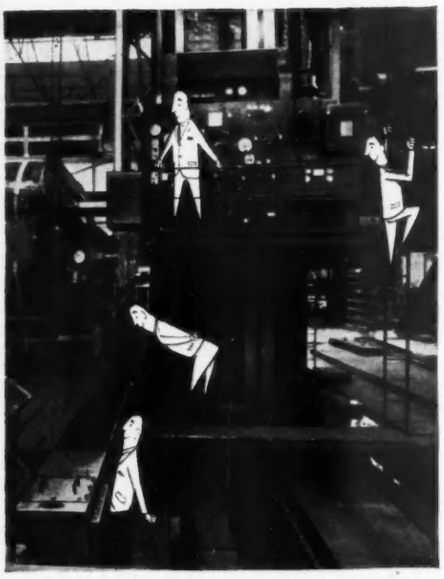

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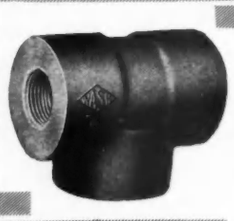

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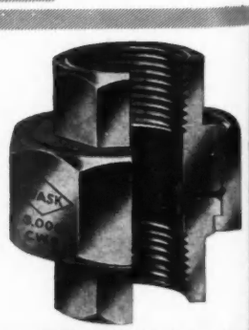

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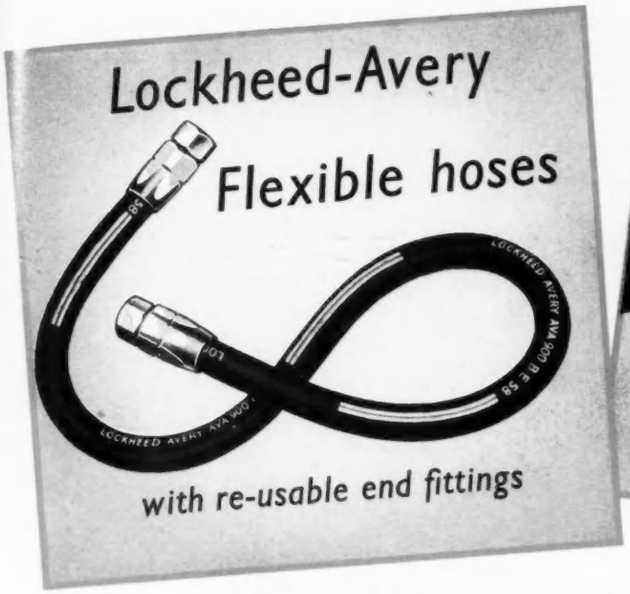

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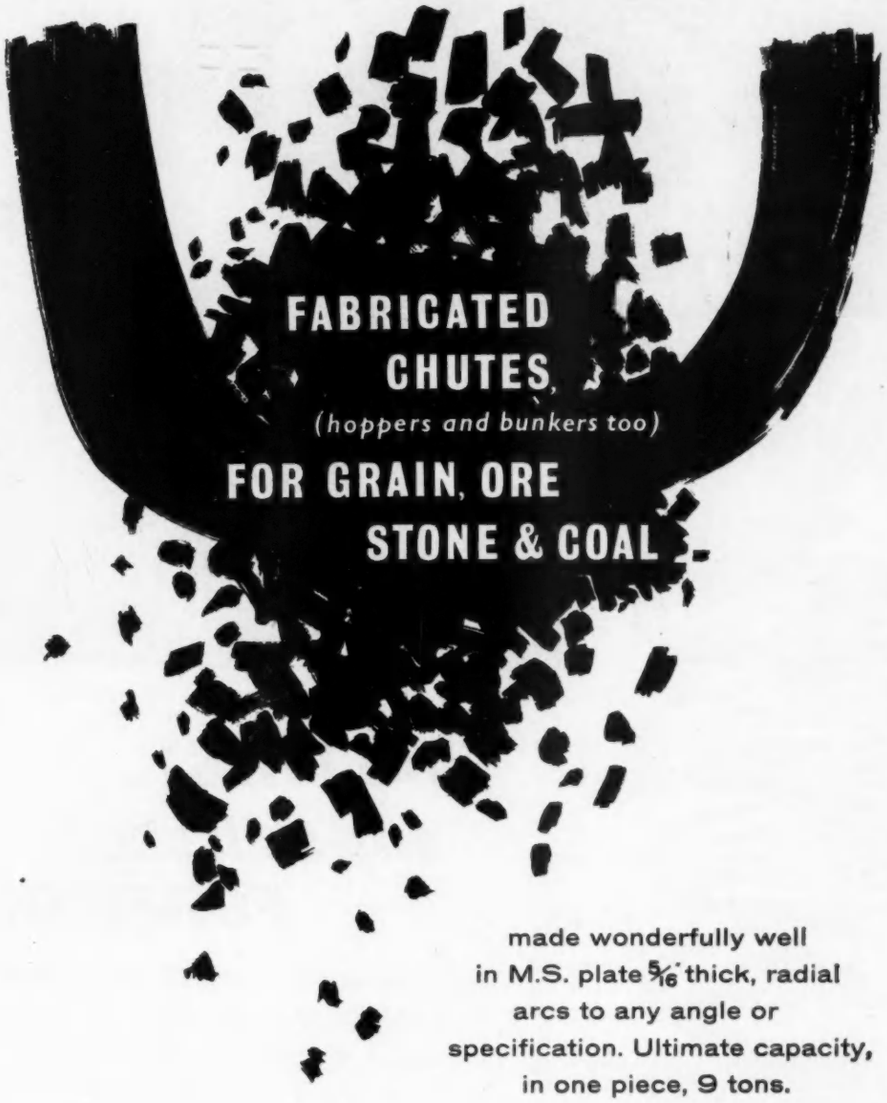

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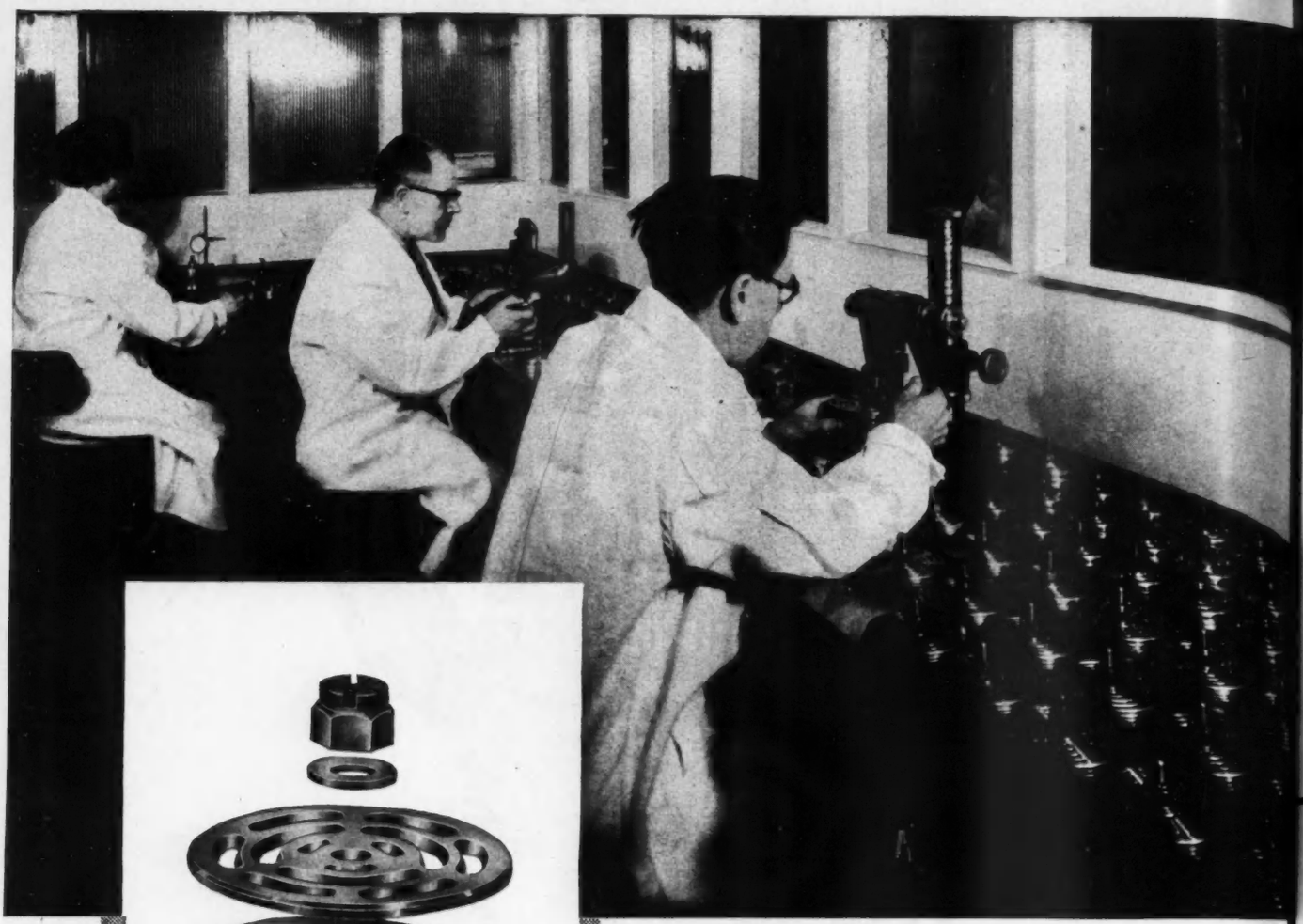

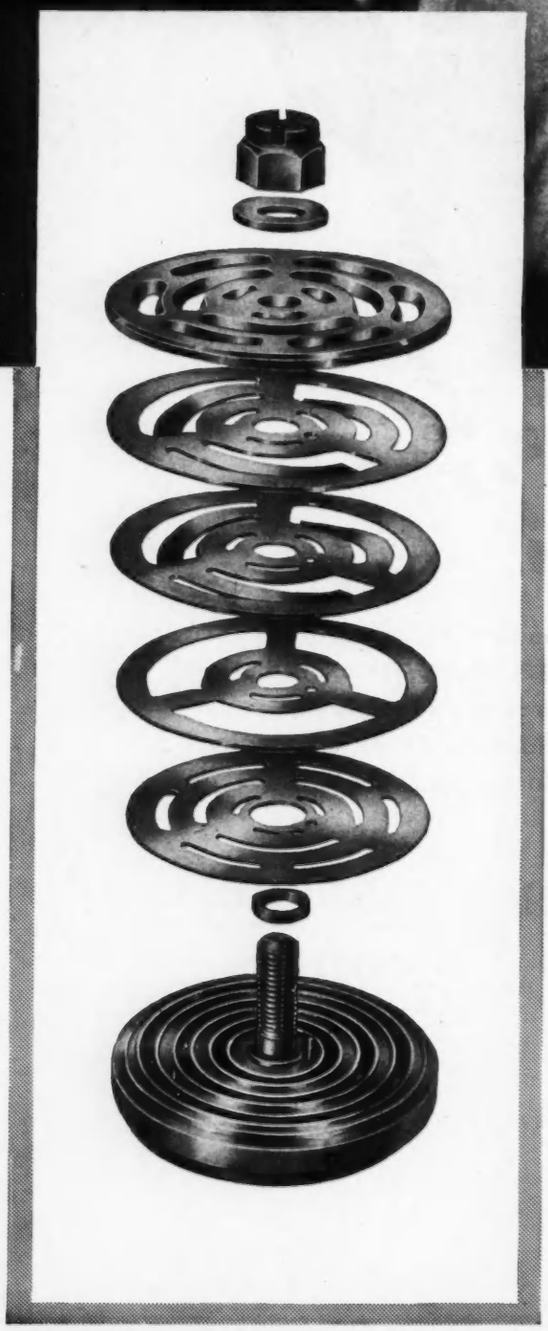

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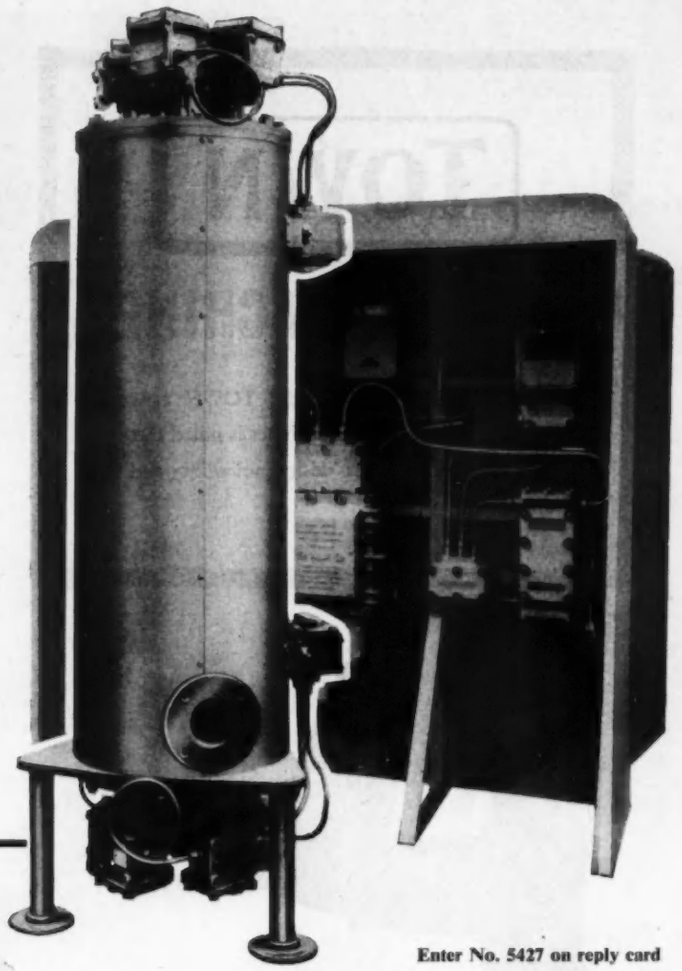

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They are designed to suit their load, with the conditions in which they have to travel borne in mind from the outset.

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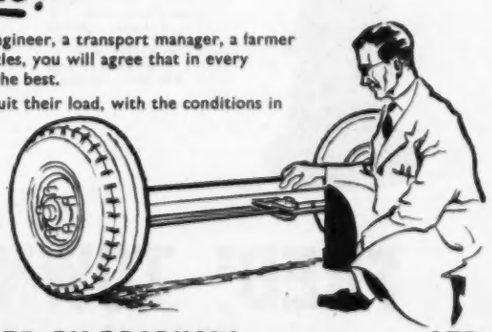

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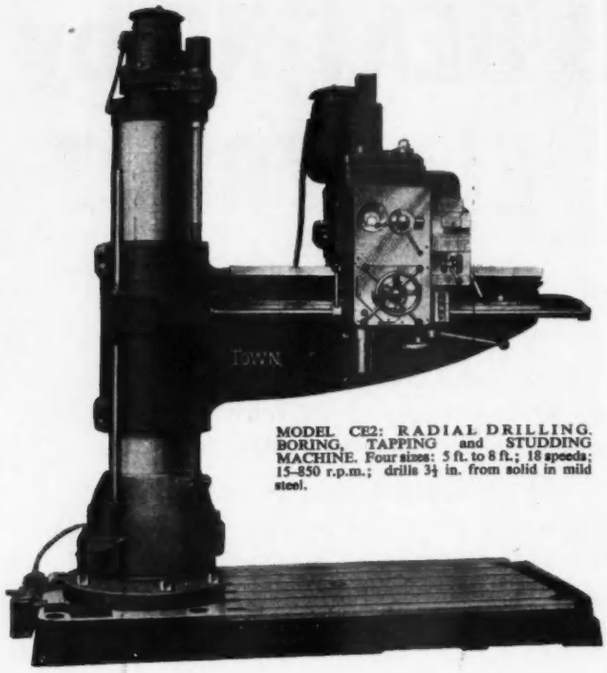
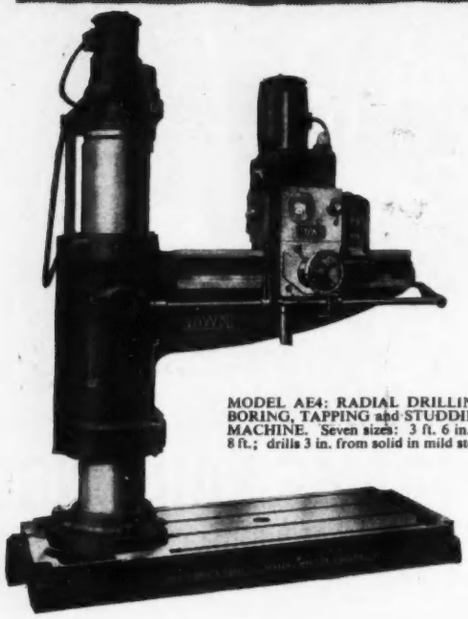
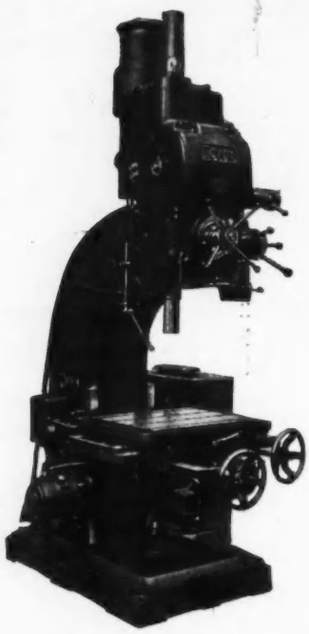


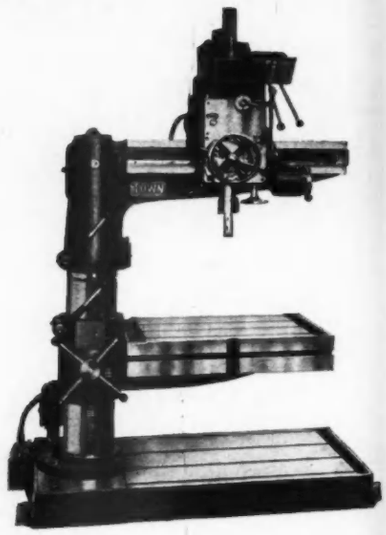
MODEL CE2: RADIAL DRILLING, BORING, TAPPING and STUDDING MACHINE. Four sizes: 5 ft. to 8 ft.; 18 speeds; 15–850 r.p.m.; drills 3¼ in. from solid in mild steel.



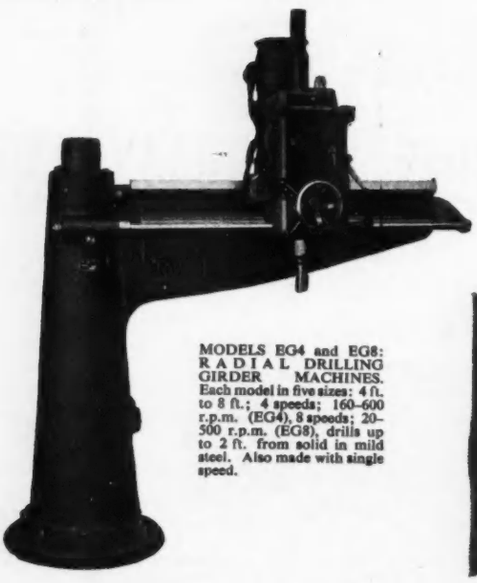
MODEL AE4: RADIAL DRILLING, BORING, TAPPING and STUDDING MACHINE. Seven sizes: 3 ft. 6 in. to 8 ft.; drills 3 in. from solid in mild steel.



MODEL AE2: VERTICAL DRILLING MACHINE (heavy-duty model). Two sizes: 36 in. and 42 in.; drills 3½ in. from solid in mild steel.



MODEL AE5: RADIAL DRILLING, TAPPING and STUDDING MACHINE. 42 in.. drills 1¼ in. from solid in mild steel or 1½ in. in cast iron.



MODELS EG4 and EG8: RADIAL DRILLING GIRDER MACHINES. Each model in five sizes: 4 ft. to 8 ft.; 4 speeds; 160–600 r.p.m. (EG4), 8 speeds; 20–500 r.p.m. (EG8), drills up to 2 ft. from solid in mild steel. Also made with single speed.

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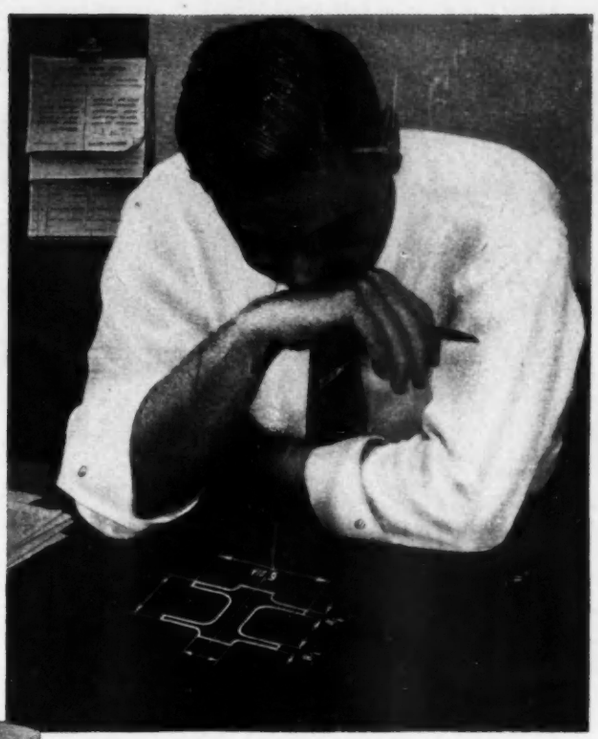

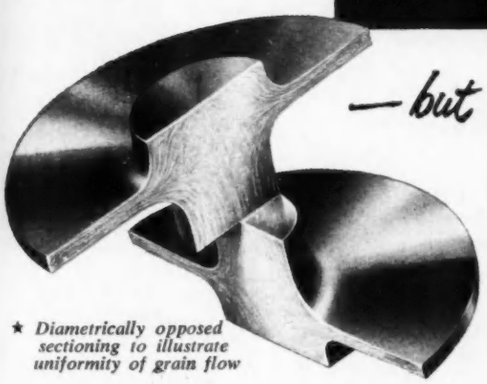

★ *Diametrically opposed sectioning to illustrate uniformity of grain flow*

—but could he get it?

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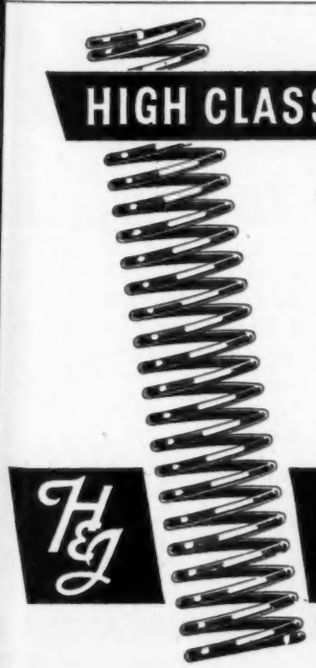

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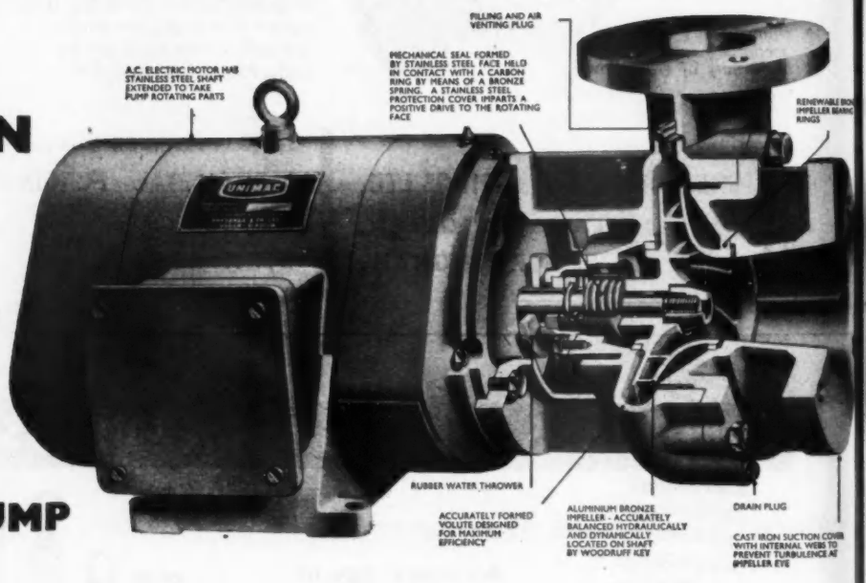
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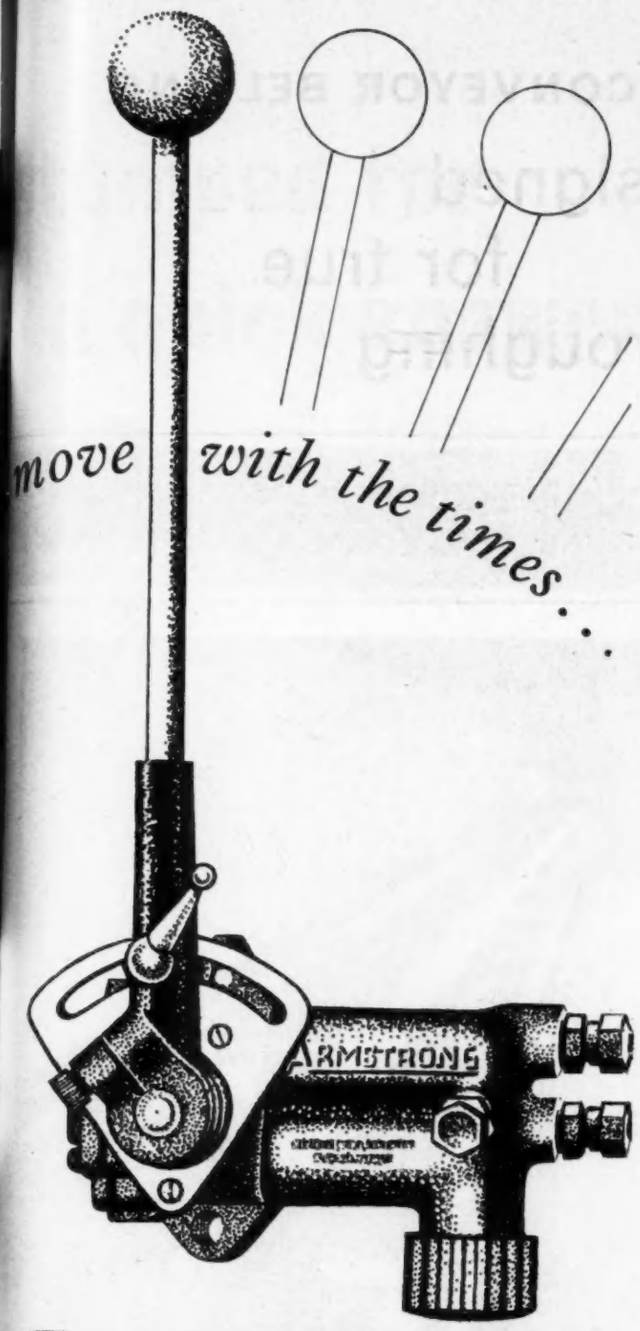

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"SAMICA" is mica paper having a high degree of uniformity in both electrical and mechanical characteristics. Samicanite and Samicafolium are insulating materials prepared by impregnating "Samica" with high grade bonding agents, with or without the addition of backing material.

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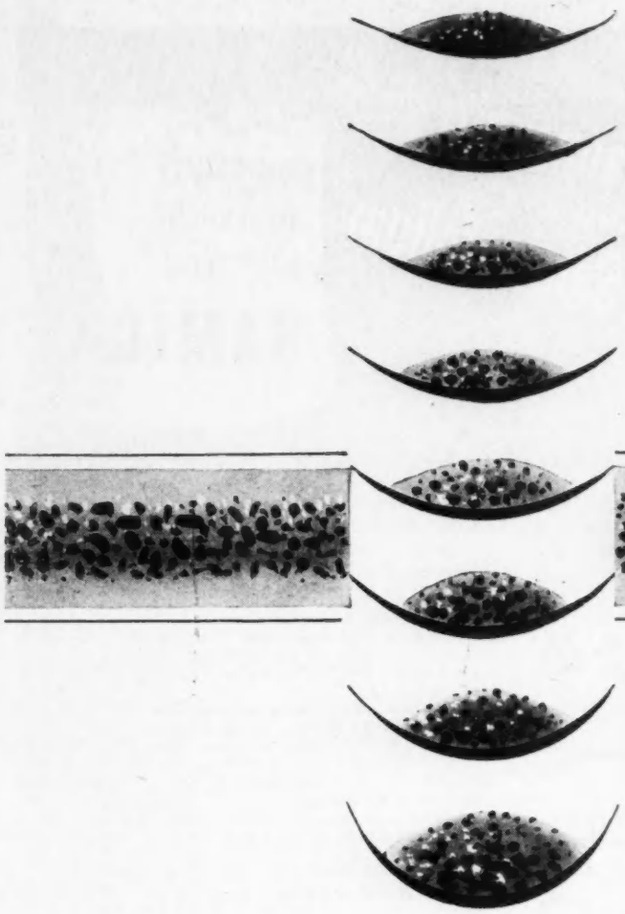

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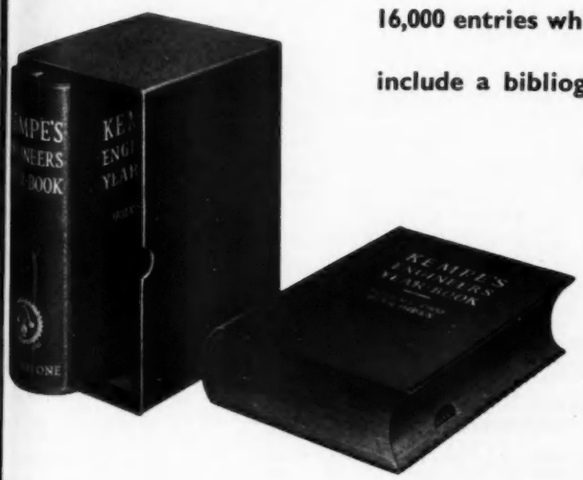

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PUBLIC APPOINTMENTS

UNIVERSITY OF SYDNEY

SENIOR LECTURESHIP AND LECTURESHIPS IN ELECTRICAL ENGINEERING

Applications are invited for the following positions in the School of Electrical Engineering :
(a) SENIOR LECTURESHIP IN ELECTRICAL ENGINEERING. Candidates should be well qualified in Electrical Engineering and have proven research ability. The successful applicant will be required to teach at undergraduate and post-graduate levels and to undertake research. Preference will be given to a candidate who is interested in undertaking research in the field of radio-astronomy.
(b) LECTURESHIPS (TWO) IN ELECTRICAL ENGINEERING. Candidates should be well qualified in Electrical Engineering or Physics and able to undertake teaching and research in one or more of the fields of power engineering, electronics, solid state circuits and devices, circuit theory, control systems, computers or energy conversion.
The salary for a Senior Lecturer is within the range £A2550 by £A95 to £A3000 per annum ; for a Lecturer within the range £A1730 by £A105 to £A2435 per annum. In each case cost of living adjustments (at present £A47 p.a.) will be allowed. The salary is subject to deductions under the State Superannuation Act. The commencing salary will be fixed according to the qualifications and experience of the successful applicants.
Further particulars and information as to the method of application may be obtained from the Secretary, Association of Universities of the British Commonwealth (Branch Office), Marlborough House, Pall Mall, London, S.W.1.
Applications close in Australia and London on 1st March, 1962. E5239

UNIVERSITY OF HONG KONG

LECTURESHIP IN MECHANICAL ENGINEERING

Applications are invited for the abovementioned post. Applicants must be graduates of a British Commonwealth University or of equivalent status, and should preferably be Corporate Members of the Institution of Mechanical Engineers. The successful candidate will be required to teach engineering subjects, including Fluid Mechanics, to degree level, and to supervise research in this field.
Annual salary (superannuable) is £2150 by £75 to £2825 (man) or £1600 by £60 to £2140 (woman). The equivalent of income tax in the Colony is comparatively low.
Air passages (or first class sea passages of equivalent cost to tourist air passages) are provided for expatriate staff on first appointment and leaves. Accommodation at reasonable rental is provided for those recruited from abroad.
Further particulars and information as to the method of application may be obtained from the Secretary, Association of Universities of the British Commonwealth (Branch Office), Marlborough House, Pall Mall, London, S.W.1.
Applications close, in Hong Kong and London, on 31st January, 1962. E5238

NORTH WEST METROPOLITAN REGIONAL HOSPITAL BOARD

ENGINEER'S DEPARTMENT

TRACER

TRACER required for Engineer's Department. Experience preferred, but school leaver to train considered.
Salary : age 16, £240 ; age 18, £290 ; age 21, £380, age 26 and over, £515, on scale rising to £595.
Apply, stating age, education and experience (if any) with names of two referees, to Secretary North West Metropolitan Regional Hospital Board, 40, Eastbourne Terrace, W.2, by 8th January quoting reference 13. E5242

MIDDLESEX COUNTY COUNCIL

EDUCATION COMMITTEE

HENDON TECHNICAL COLLEGE THE BURROUGHS, HENDON LONDON, N.W.4

Principal : E. WILLIAMS, B.Sc., Ph.D., F.R.I.C

MECHANICAL ENGINEERING DEPARTMENT

SENIOR LECTURER

SENIOR LECTURER to specialise in the subjects of either Strength of Materials or Theory of Machines. Teaching up to Honours Degree standard is required, together with some experience of individual project work of post-graduate standard.
Applications would also be considered from persons of outstanding ability who wish to offer another specialist mechanical engineering subject in place of one of the above.
Applicants for the above post should hold a good degree or equivalent qualification, and have suitable industrial experience ; good experience of research methods would be an advantage.
Salary scales (from 1st January, 1962) : Senior Lecturer : £1845 to £2060 per annum.
Anyone interested in the above post can obtain application forms and more information from the Clerk to the Governing Body, Town Hall, London, N.W.4. Application forms should be returned within 14 days of the appearance of this advertisement.

C. E. GURR, M.Sc., Ph.D.,
E5252 Chief Education Officer.

ENGINEERING CADETSHIPS IN THE CIVIL SERVICE

A number of ENGINEERING CADETSHIPS are being offered in various Government Departments to men and women under 26 on 31st December of year in which application is made (with extension up to 3 years for Forces service) who have (or expect to have within six months) a first or second class honours degree, or Diploma in Technology, in engineering or physics. Exceptionally, applicants who have served a student apprenticeship or similar course, and who are academically qualified for graduate membership of the professional engineering institutions will be considered. Selection will be by interview.
Successful candidates will be given a comprehensive course of engineering training lasting up to three years and designed to supply the basis of practical experience essential to a professional engineering career. Cadets who satisfactorily complete the course and obtain graduate membership of the appropriate professional institution will be appointed to the basic grade of professional engineer in the Civil Service. Promotion to the main grade of professional engineer may be expected after two to six years in the basic grade. Further promotion prospects are good. Employment will be in a pensionable capacity from the outset.
The salary (national scale) during training is £738 (1st year), £770 (2nd year), £801 (3rd year). Basic grade engineers receive from £858 (at age 24) to £1258 (at 34) rising to £1430, and main grade engineers £1456 to £1950.
For further particulars and an application form, write to Civil Service Commission, 17 North Audley Street, London, W.1, quoting S/565
E5249

DEPARTMENT OF MAIN ROADS

NEW SOUTH WALES, AUSTRALIA

CIVIL ENGINEERS

Applications are invited from Graduates (or undergraduates in their final year) in Civil Engineering of a recognised British or Irish University for appointment to the staff of the Department of Main Roads, New South Wales, the State Road Authority for construction of roads and bridges.
On appointment, applicants may be engaged at the Department's Head Office, Sydney, on the design of reinforced concrete and steel bridges, or on main road constructions and maintenance either in the Metropolitan Area or the country.
Commencing salary according to qualifications and experience will be within the range £A1359 to £A1684 per annum, with annual progression, subject to technical competence to £A2434 per annum. Appointees will be eligible to contribute to the State Superannuation Fund after six months.
Appointee's full fare from England to Australia will be met by the Department, subject to a three years' service guarantee bond being completed. Appointment will be subject to passing a medical examination and preference will be given to applicants not more than 30 years of age.
Applications should be made on forms obtainable from the Agent General for New South Wales, 56, Strand, London, W.C.2. Please quote No. 44/31 when writing. E5176

ROAD RESEARCH LABORATORY (D.S.I.R.)

HARMONDSWORTH, MIDDLESEX

CIVIL ENGINEERS AND PHYSICISTS

Road Research Laboratory (D.S.I.R.), Harmondsworth, Middlesex, requires CIVIL ENGINEERS and PHYSICISTS, in the Senior Scientific and Scientific Officer grades for work in the Tropical Section. Duties concern problems of road building and road transport in tropical and sub-tropical areas, involving soil mechanics, traffic engineering, and economics studies. Section is based at Harmondsworth and work involves regular visits overseas with, in some instances, postings for periods of one or two years on specific projects : usual Foreign Service Allowances apply. Qualifications: 1st or 2nd Class Honours degree. For S.S.O. some years of appropriate post-graduate research or equivalent experience is required. Salary—within range : S.O.: £773 to £1267 ; S.S.O.: £1392 to £1714. Prospects of promotion to Principal Scientific Officer (range up to £2478) with possibility of higher posts. Laboratory is expected to move to Crowthorne, near Bracknell, Berkshire in 1963-64. Application form and further information from Director of Road Research (address above) quoting ROAD YXW.
E5198

BOROUGH OF HENDON

BOROUGH ENGINEER AND SURVEYOR'S DEPARTMENT

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Applications are invited for the above appointment at a commencing salary according to experience within Grade A.P.T. III (£960 to £1140 per annum, plus London Weighting).
Applicants must be capable draughtsmen experienced in the preparation of drawings and specifications for heating installations in public buildings.
Possession of an Ordinary National Certificate would be an advantage.
Pensionable post. National Scheme. Medical examination. Appointment terminable by one month's notice on either side.
Applications stating age, education, qualifications, experience, present appointment and salary, together with the names and addresses of two referees, must reach the Borough Engineer and Surveyor, Town Hall, Hendon, N.W.4, by the 12th January, 1962.
Canvassing will disqualify.

R. H. WILLIAMS,
Town Hall, Town Clerk.
Hendon, N.W.4. E5253

TENDERS

HYDRO-ELECTRIC CONSTRUCTION PROJECTS

TENDER ENQUIRY NO. HCP/SVHEP-7/NOVEMBER 1961

The Office of the Chief Engineer, Hydro-Electric Construction Projects, Post Bag No. 60, Bangalore, 1, India, invites TENDERS for :

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For the SUPPLY of THREE NOS CENTRIFUGAL PUMP SETS, 2500 g.p.m., capacity against 120ft. head, each complete with motors, pipings, valves, strainers and switchgear, &c., required for Sharavathi Power House.
Copies of the Tender specifications can only be had direct from the Chief Engineer, Hydro-Electric Construction Projects, Race Course Cross Road, Post Bag No. 60, Bangalore 1, India, on payment of Rs. 50/-, i.e. £3 15s. plus 4s. 6d. postal charges per set. The cost of the Tender documents are not refundable.
Tenders are to be returned direct to the Chief Engineer, Hydro-Electric Construction Projects, Race Course Cross Road, Post Bag No. 60, Bangalore 1, India, and not to this office and should reach him by 1st February, 1962.
Only the manufacturers (including their constituents or Associates authorised to commit them) or their accredited Agents who are in a position to supply the requirements from their own or their Principal's manufacturers are invited to quote.
Specimen copy of the above enquiry can be seen at India Store Department, Engineering Branch, Bromyard Avenue, Acton, W.3, under the following reference S.3704/61/NSC/ENG.1.
E5259

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STRAIGHT BEVEL GEAR CUTTING MACHINE

The Director General, India Store Department, Government Building, Bromyard Avenue, Acton, London, W.3, invites TENDERS for the following :

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Only the manufacturers (including their constituents or Associates authorised to commit them) or their accredited Agents who are in a position to supply the requirements from their own or their Principal's manufacturers are invited to quote.
Forms of Tender which are returnable on Monday, 12th February, 1962, may be purchased from C.D.N. Section at the above address at a cost of 10s. which is not returnable. In your application for Tender forms please quote reference 2104/61/ENG.1. E5260

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ENGINEER SURVEYORS capable of working from home on their own initiative are required by The Northern and Employers' Group as lifting machinery Surveyors in London, Liverpool, Newcastle and Cardiff. Minimum qualification Higher National Certificate and preferably applicants should have served an apprenticeship with a firm of lifting machinery manufacturers. Progressive salary scale at present £825 rising to £1225 plus expenses and allowances. Car provided. Non-contributory pension scheme and other Staff Schemes.—Applicants should write giving full details and stating area preferred to The Joint General Managers, The Northern and Employers' Group, No. 1 Moorgate, E.C.2. E5256 SV

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THE NORTHERN AND EMPLOYERS' GROUP have vacancies for Engineer Surveyors in London, Manchester, Bristol, Edinburgh and Cambridge. Applicants should hold first class M.O.T. Certificate (Steam) and be capable of working on their own initiative from home. Progressive salary scale at present £825 rising to £1225, plus expenses and allowances. Car provided. Non-contributory pension scheme and other Staff Schemes.—Applicants should write giving full details and stating area preferred to the Joint General Managers, The Northern and Employers' Group, No. 1 Moorgate, E.C.2. E5255 SV

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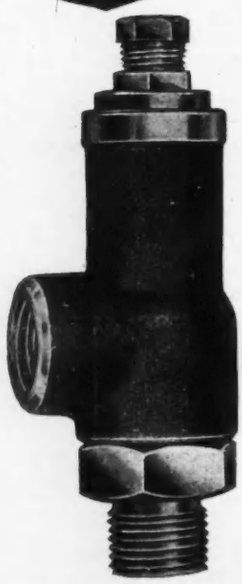

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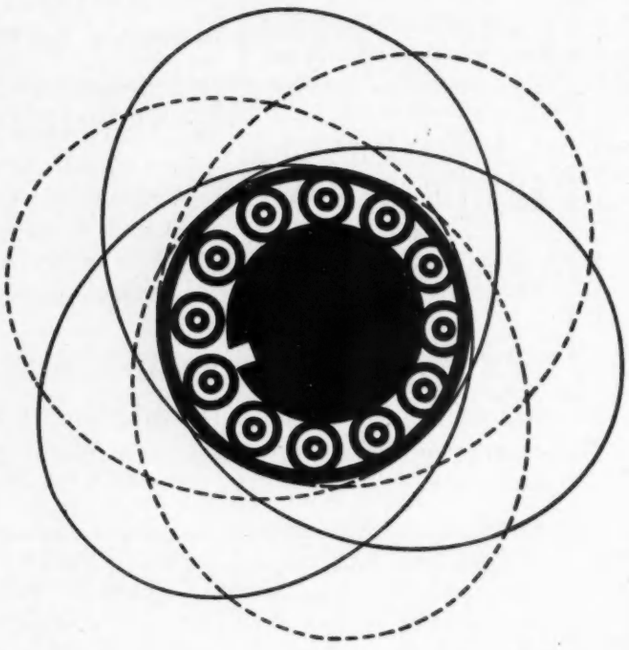

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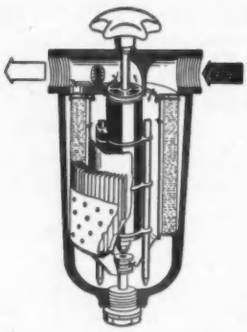

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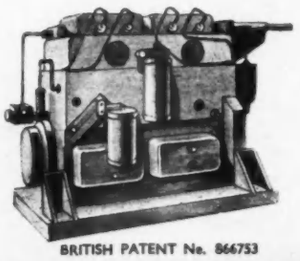

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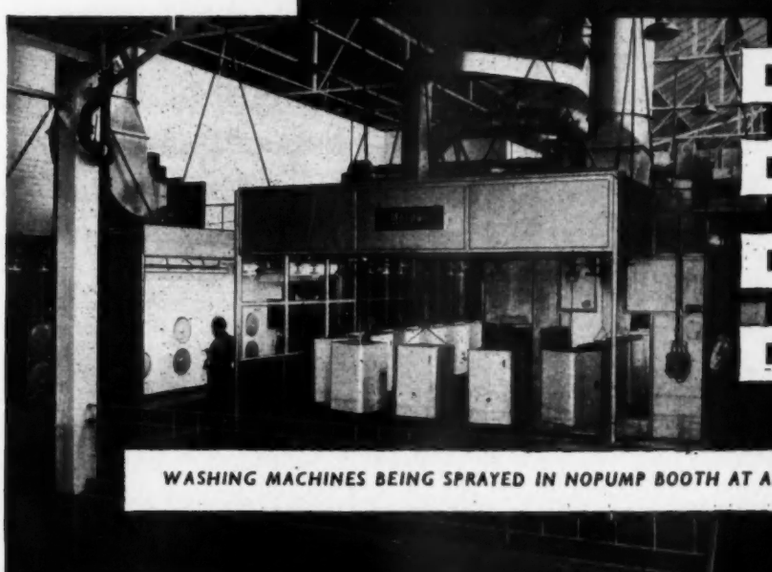

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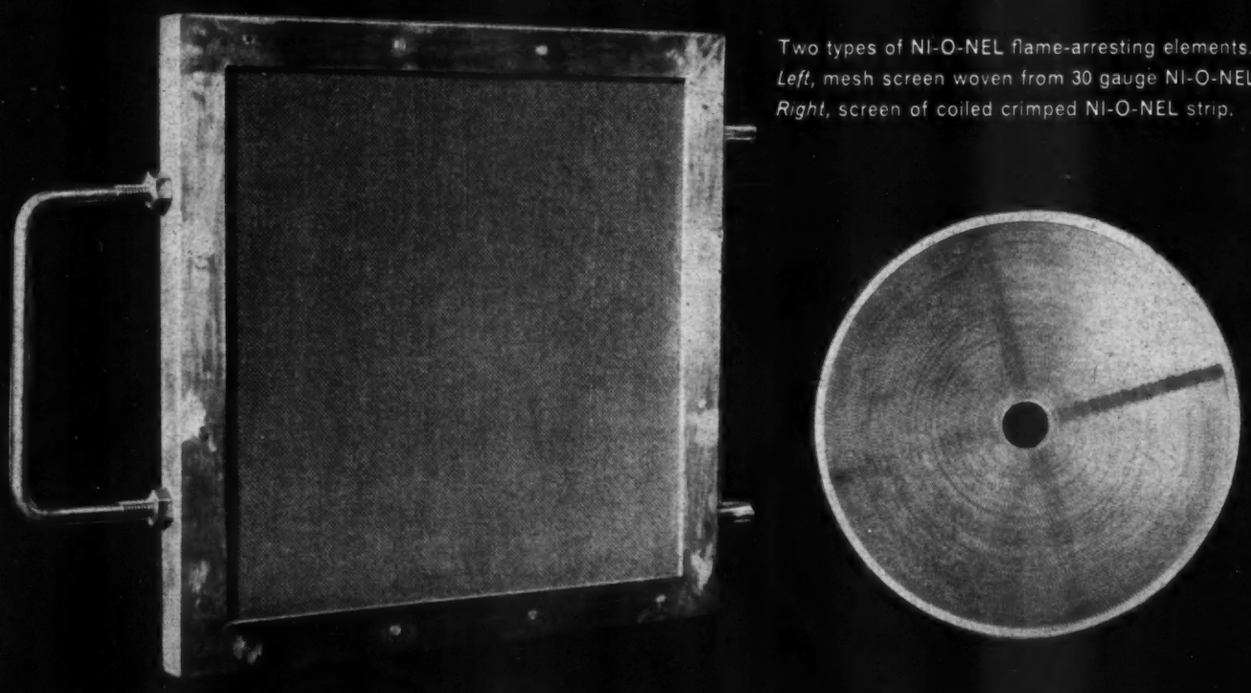

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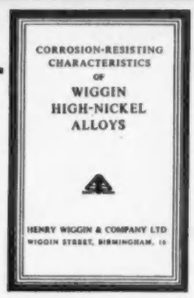

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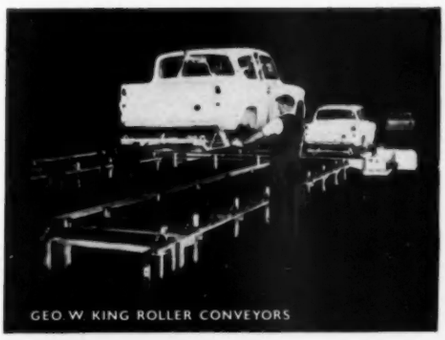

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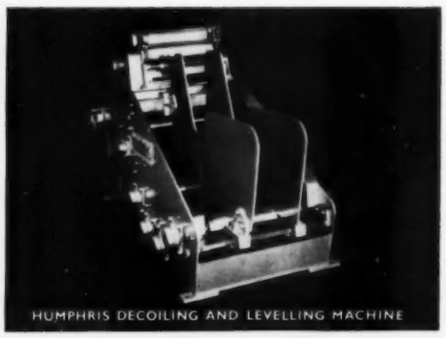

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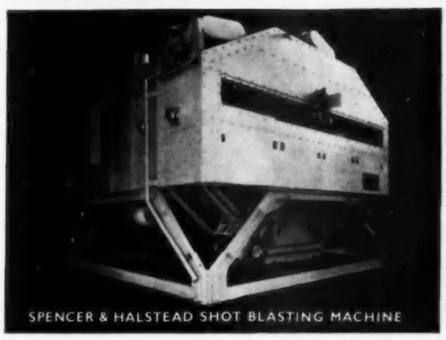

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